Solar Coronal Jets: Overview and Update

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Thanks to the Hinode 10 Organizing committee for the invitation!

Introduction: Solar Coronal Jets

- Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc.)
- Yohkoh (SXT) saw them mainly in active regions [next page].

Hinode XRT Polar Jet Properties:

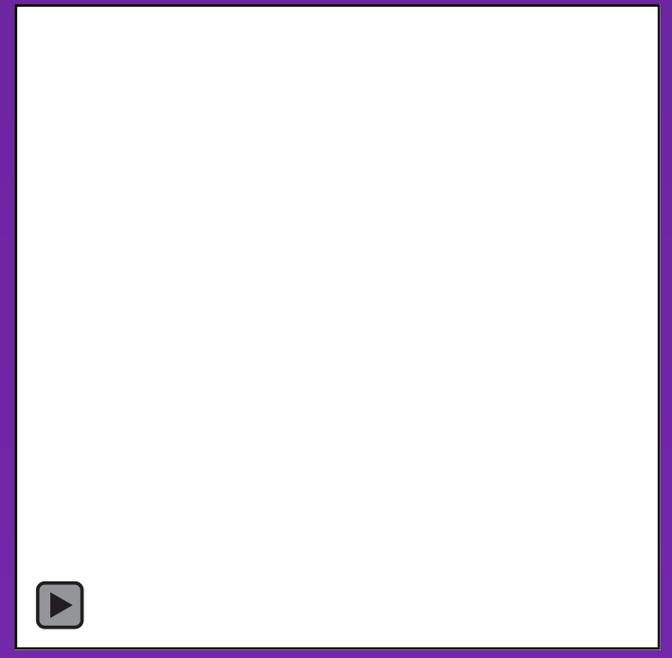
- Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- In polar coronal holes: size~50,000 km x 8000 km; rate ~60/day (Savcheva et al. 2007).
- Often have a “jet bright point” on one side of the jet’s base.
- Total energy ~10^{26}—10^{27} erg (Pucci et al. 2013).

Cirtain et al. (2007)

Yohkoh (X-ray) Jet properties

- Shimojo et al. (1996) (100 jets):
- 68% in ARs; but also QS and CHs. (Cf. Koutchmy et al. 1997 for hard-to-see 3-5 min polar “flash” events.)
- Almost all have bright bases.
- 27% show a gap (>10^4 km) between spire and jet bright point.
- <Length>= 1.5x10^5 km (large range).
- Velocity: <100~400 km/s; ave~200 km/s.
- Lifetime: 100 s~16000 s (power law).

- Shimojo & Shibata (2000):
- Thermal energy ~10^{27}—10^{29} erg.



(Thanks to K. Reeves)

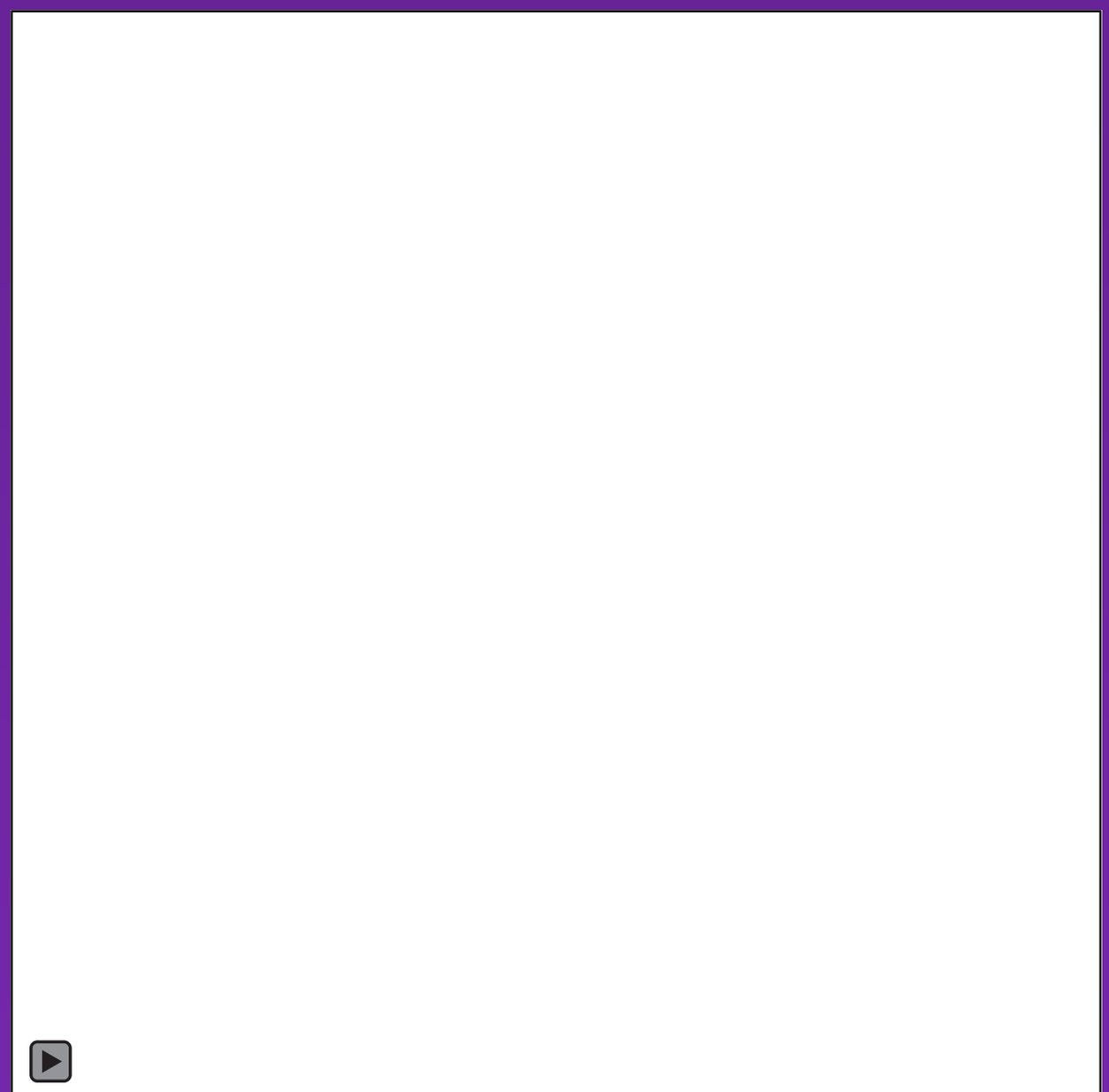
EUV Jets

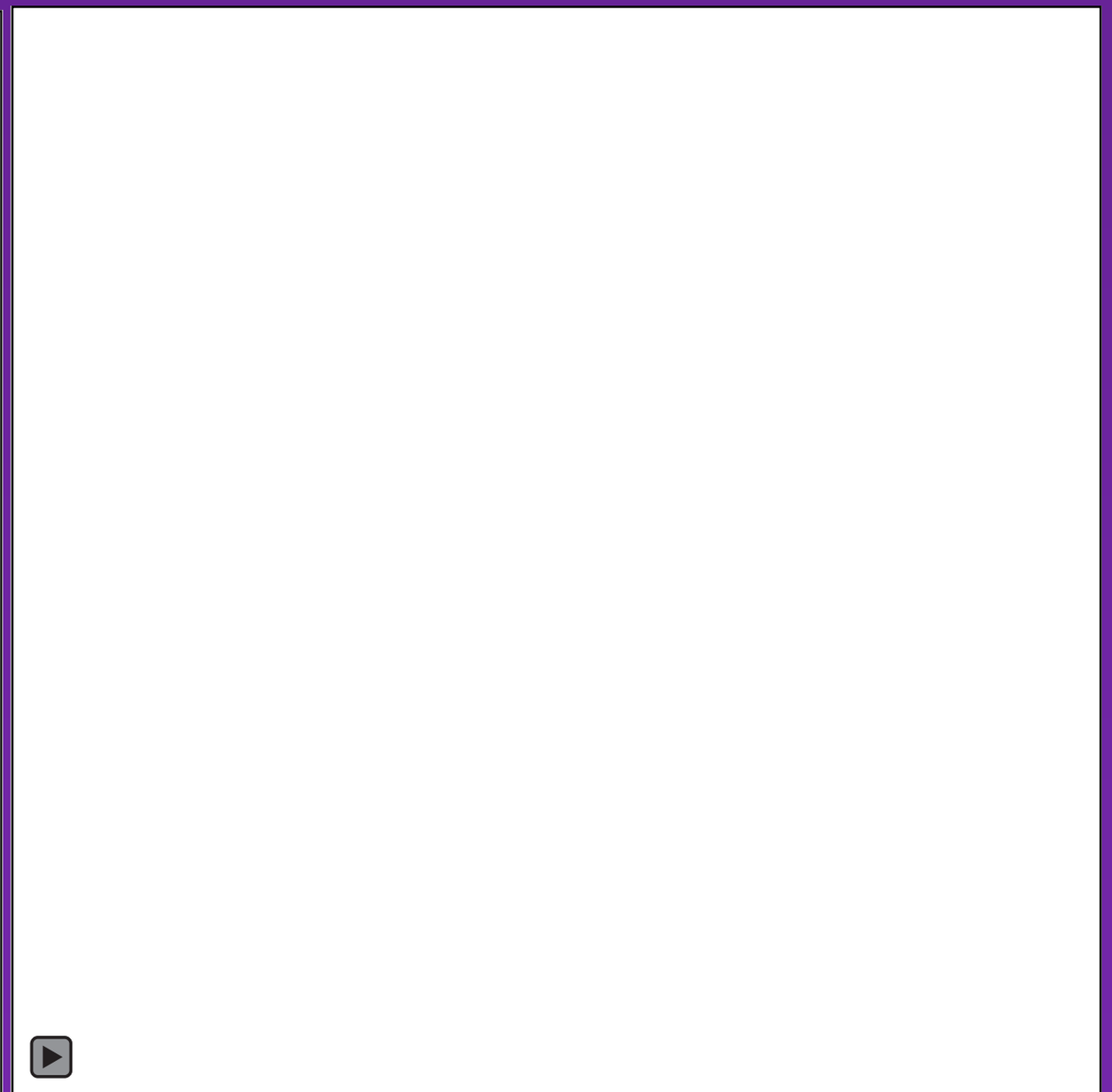
- Lots of work! (E.g. Nisticò et al. 2009, Raouafi et al. 2016.)
- Virtually all X-ray jets apparently have an EUV-jet counterpart (e.g. Moore et al. 2013, Sterling et al. 2015).
- There are EUV jets that do not have obvious X-ray-jet counterparts (e.g., Raouafi et al. 2010).
- Jets often display twisting (unwinding?) motions (many authors).

Minifilament Eruptions

XRT

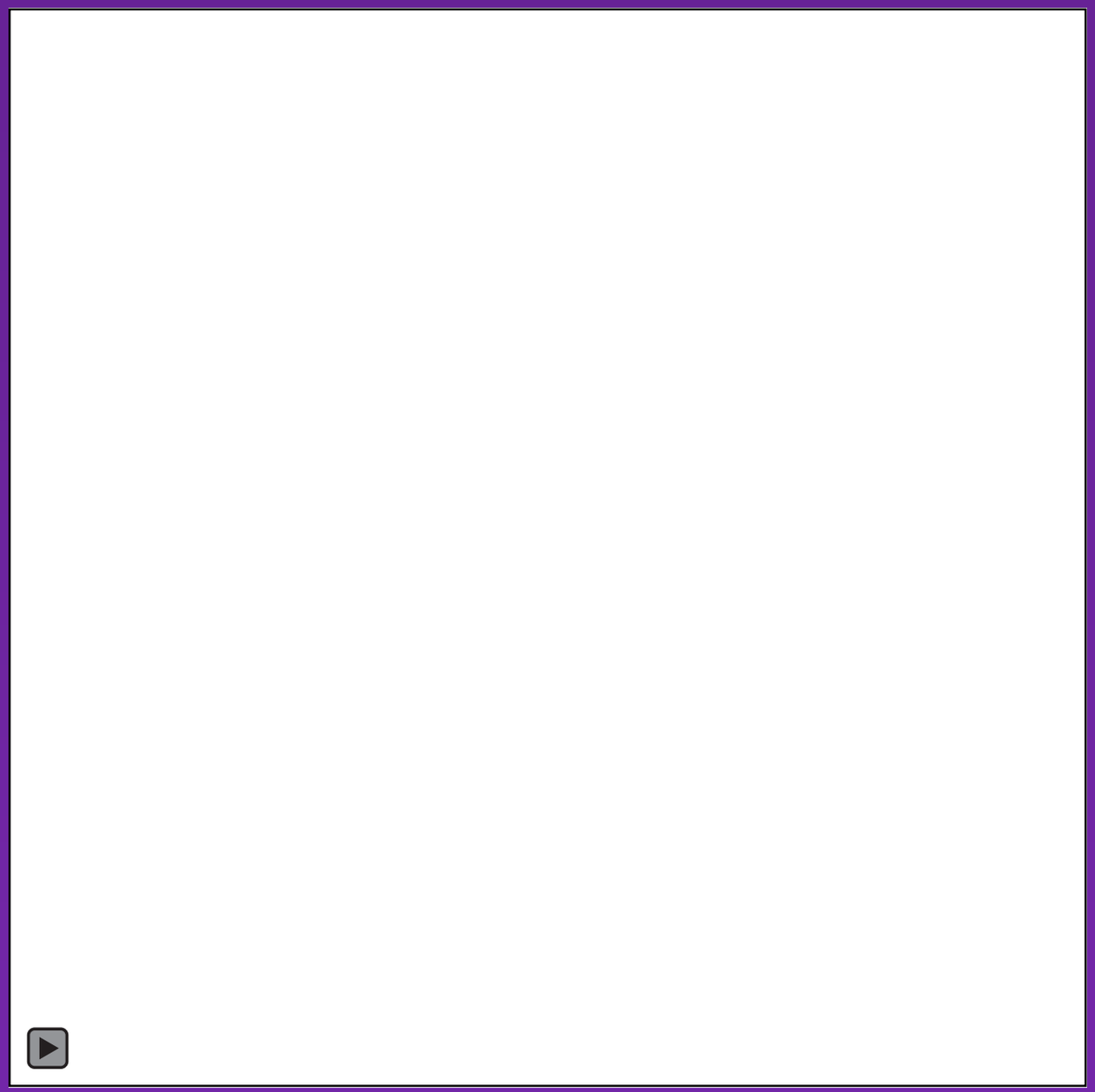
AIA 193



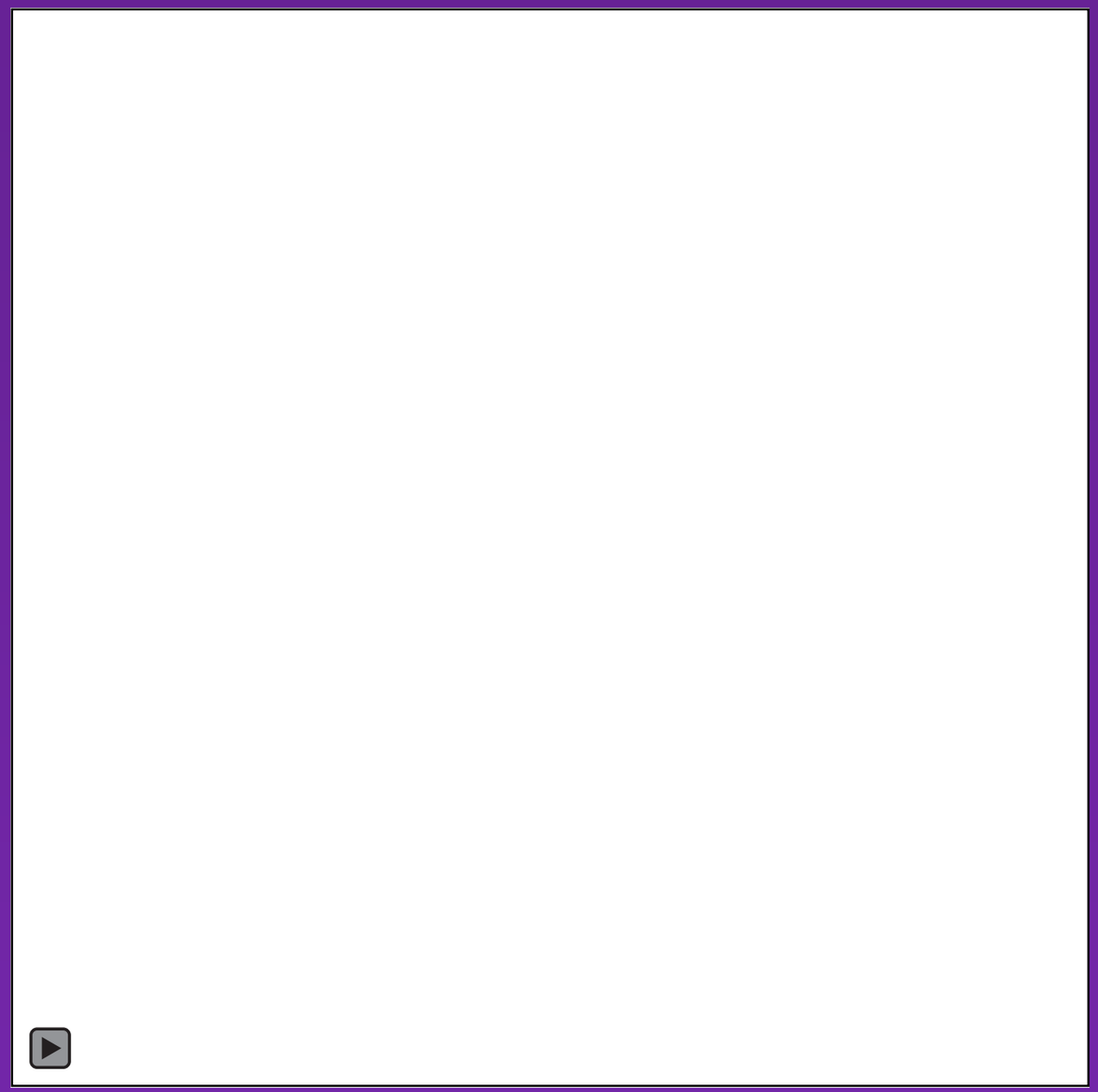


Sterling et al. (Nature, 2015): Polar CH jets.

XRT



AIA 193

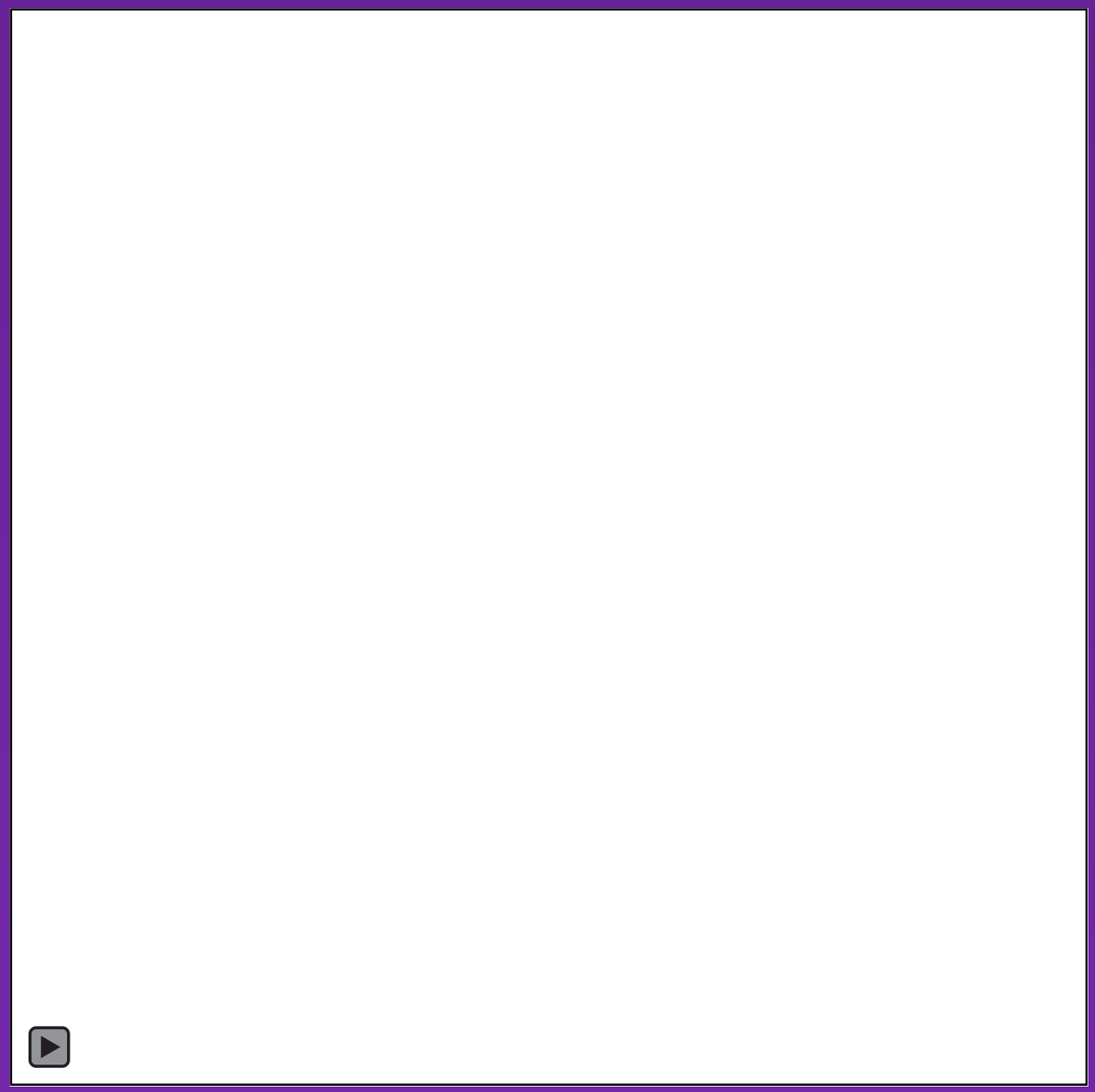


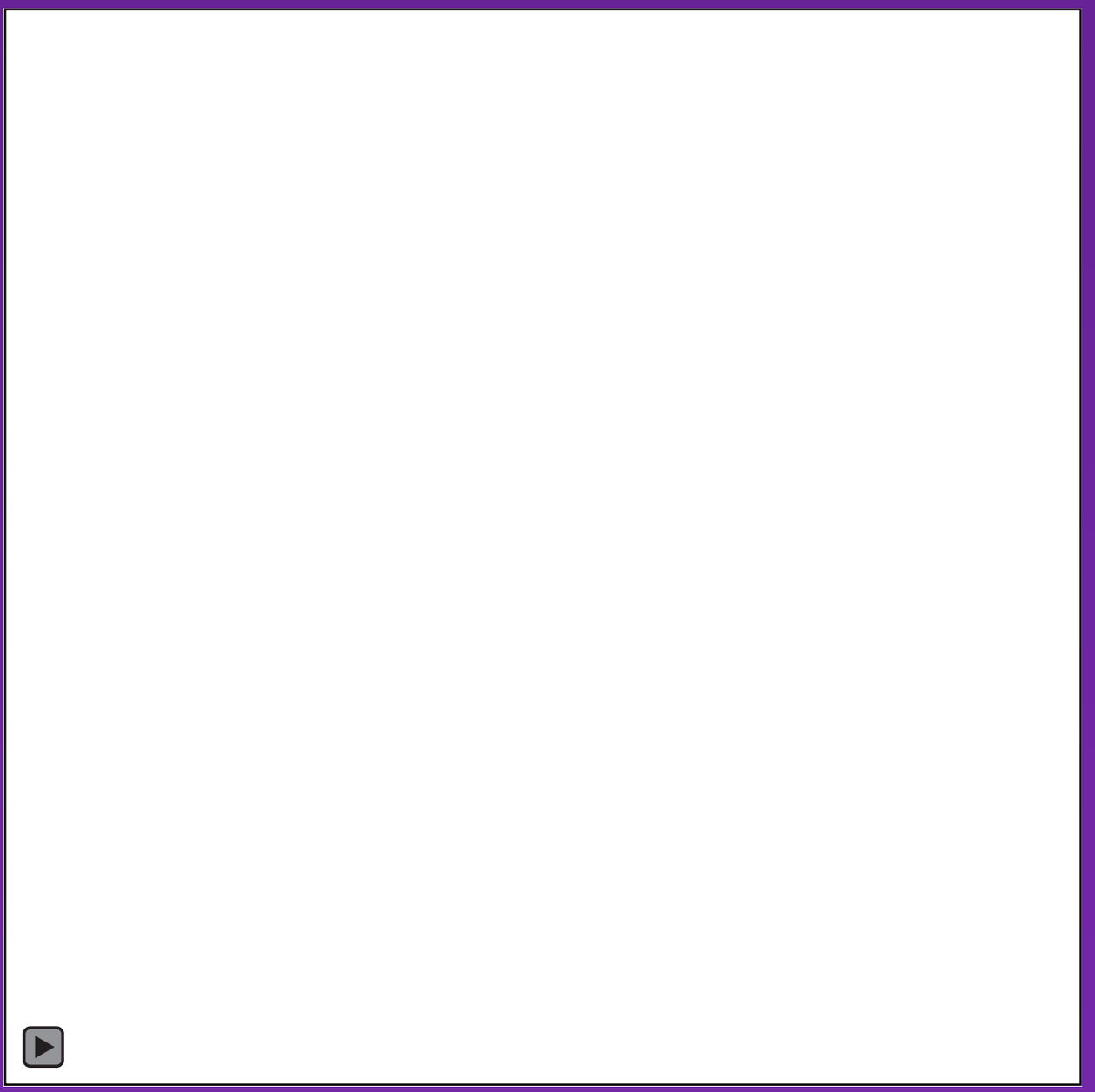
Event 3

A. Sterling

XRT

AIA 193



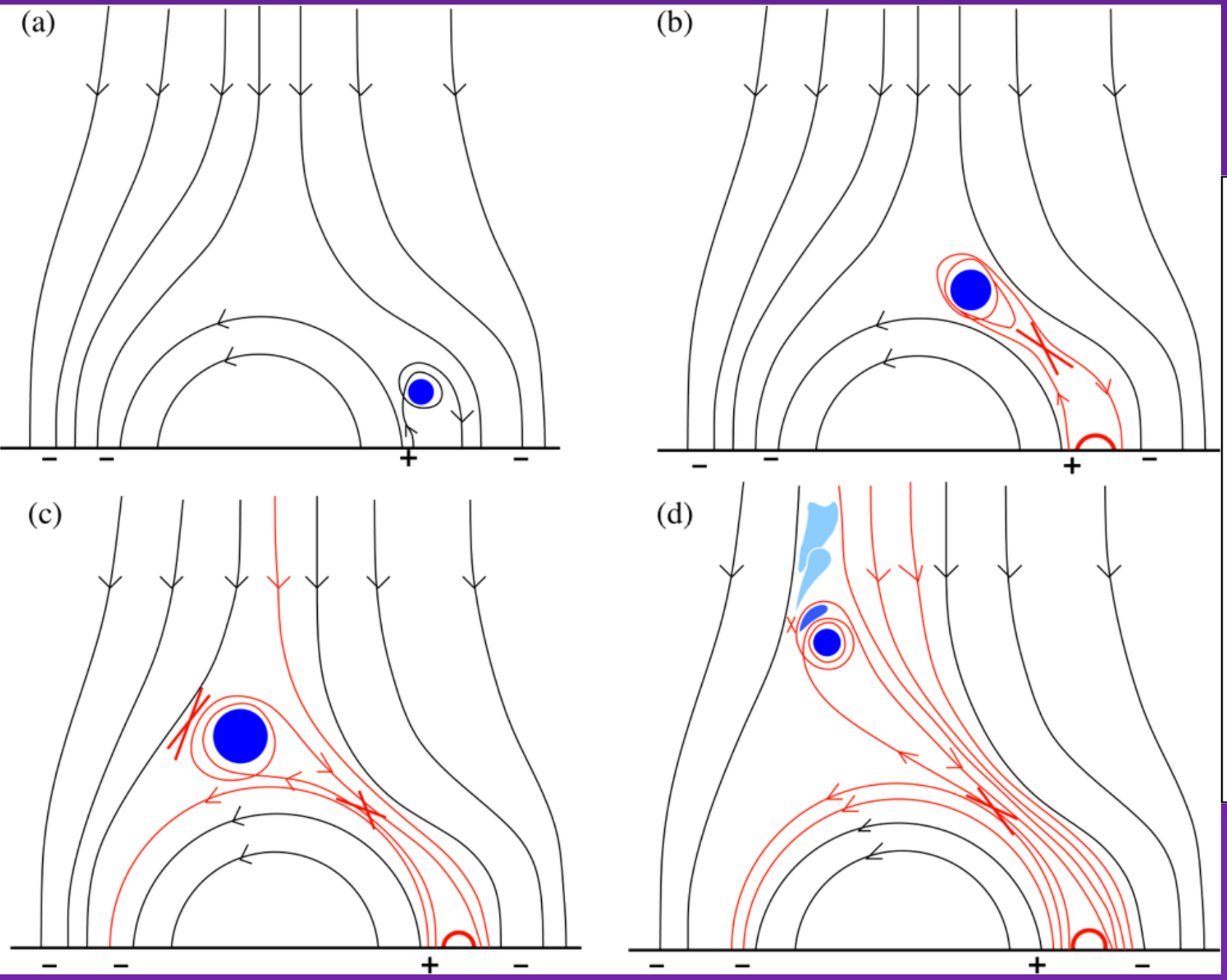


Event 12

A. Sterling

“Normal” Filament Eruption (TRACE)

A. Sterling, Feb 2016



Sterling et al. (2015, 2016, 2017): “minifilament” eruptions.

Recently modeled by Wyper, Antiochos, & Devore (Nature, 2017)

Sterling, Moore, Falconer, & Adams (2015):

- Studied 20 Hinode/XRT X-ray jets ***in polar coronal holes*** during SDO period.
- Found all events to either show or be consistent with minifilament eruptions originating from the jet bright point location, and leading to the jets. (Also, e.g., Nisticò et al. 2009, Hong et al. 2010, Raouafi et al. 2010, Shen et al. 2012, Adams et al. 2014.)
- Average size of minifilaments (seen in projection, and while starting to rise) ~8000 km.
- Therefore, the jets result from minifilament eruptions are scaled-down versions of "typical" filament eruptions, where the jet bright points correspond to flare arcades.

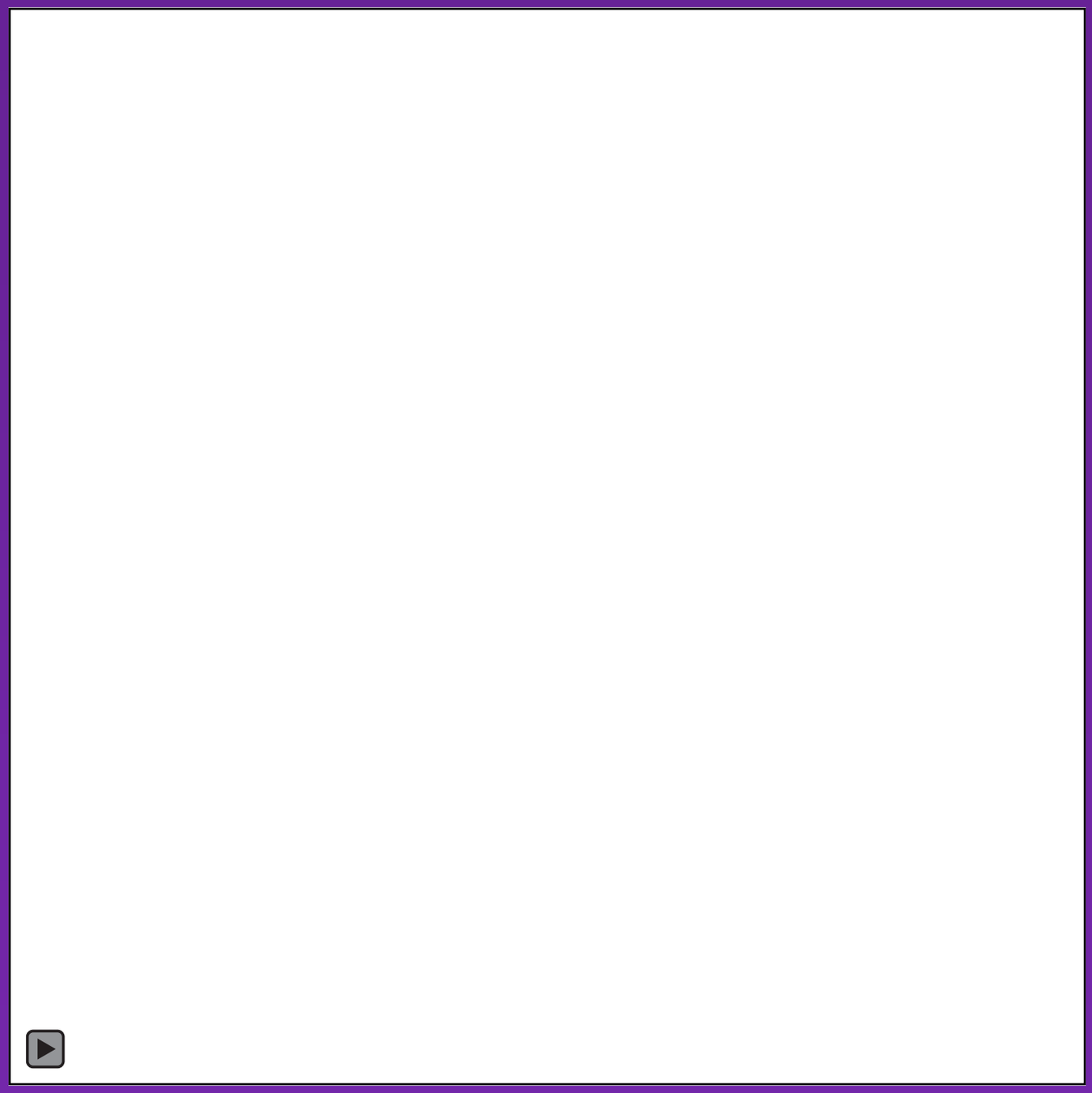
Look On Disk

First consider QS and CH on-disk jets

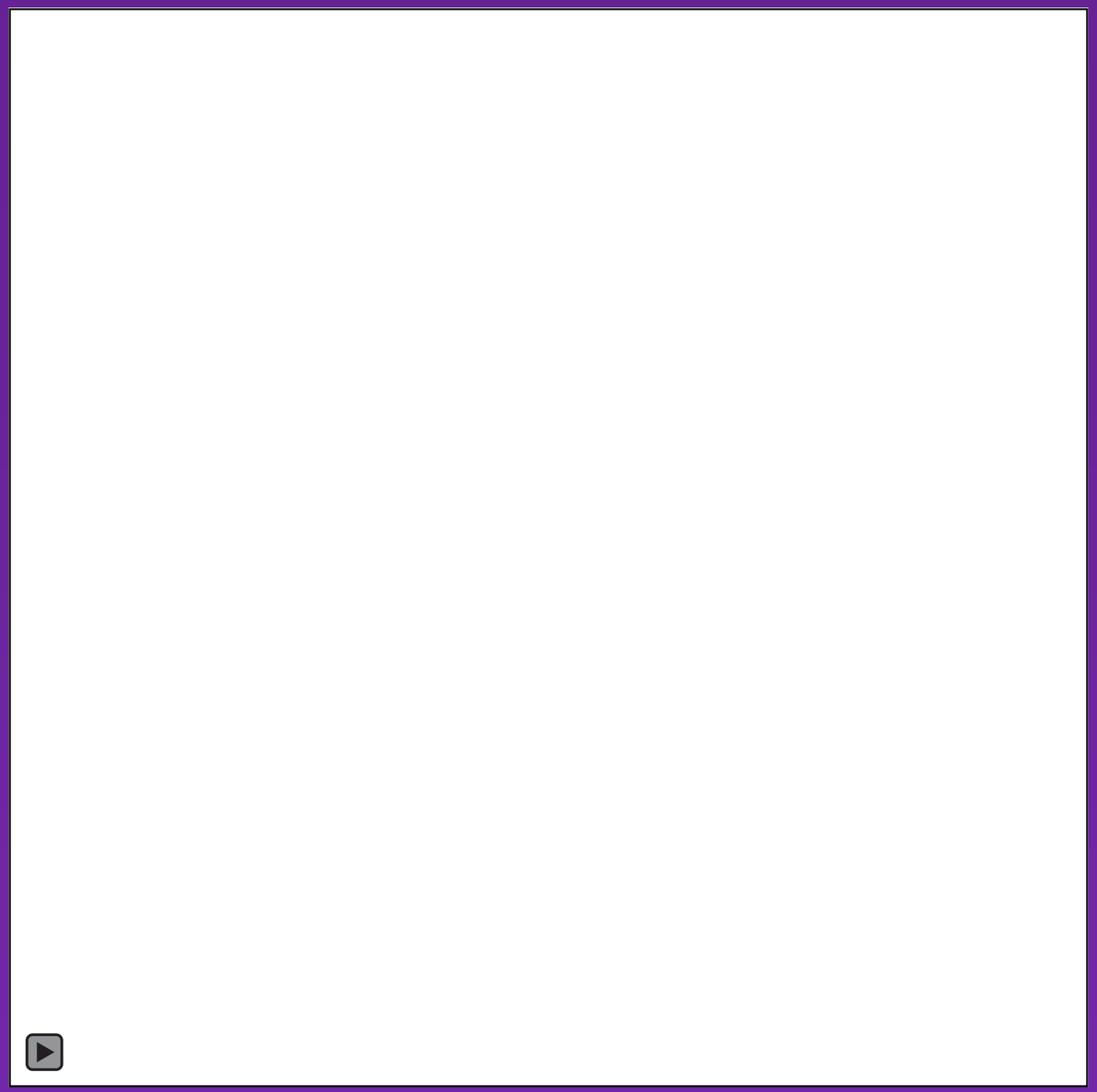
On-Disk Studies

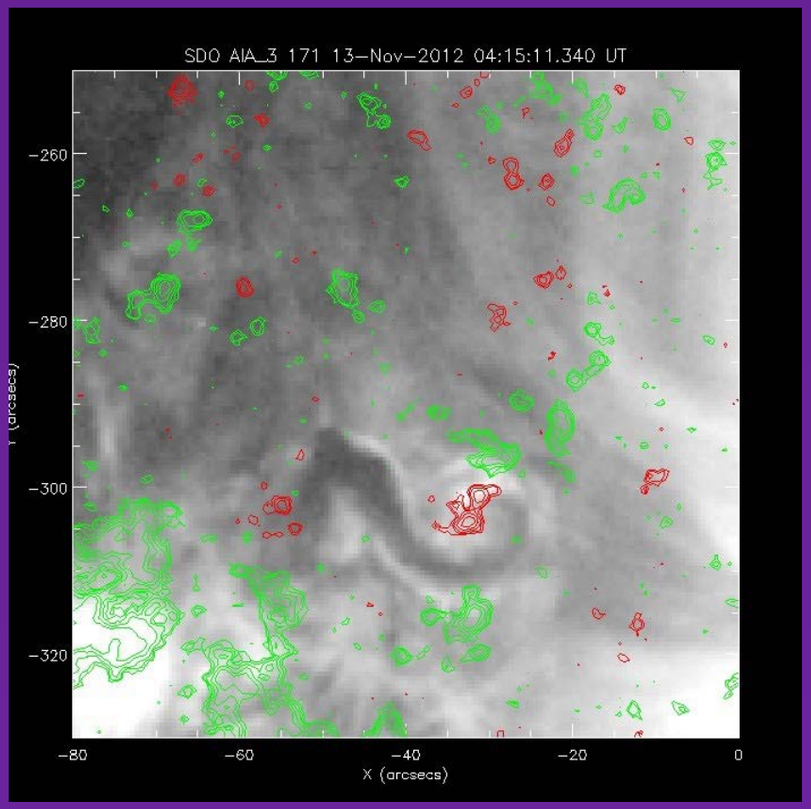
- Some examples...
- Huang et al. (2012) and Young & Muglach (2014a,b) found jet from location where flux canceled.
- Some others, e.g., Liu et al. (2011), Shen et al. (2012), and Hong et al. (2012) found jets from location of emerging flux+flux cancelation.
- Adams et al. (2014) found no emerging flux in the jet region. Filament erupted from location where flux canceled.

On-Disk Jets (QS Example)



Panesar et al. (2016, ApJL)

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Y (arcsecs)
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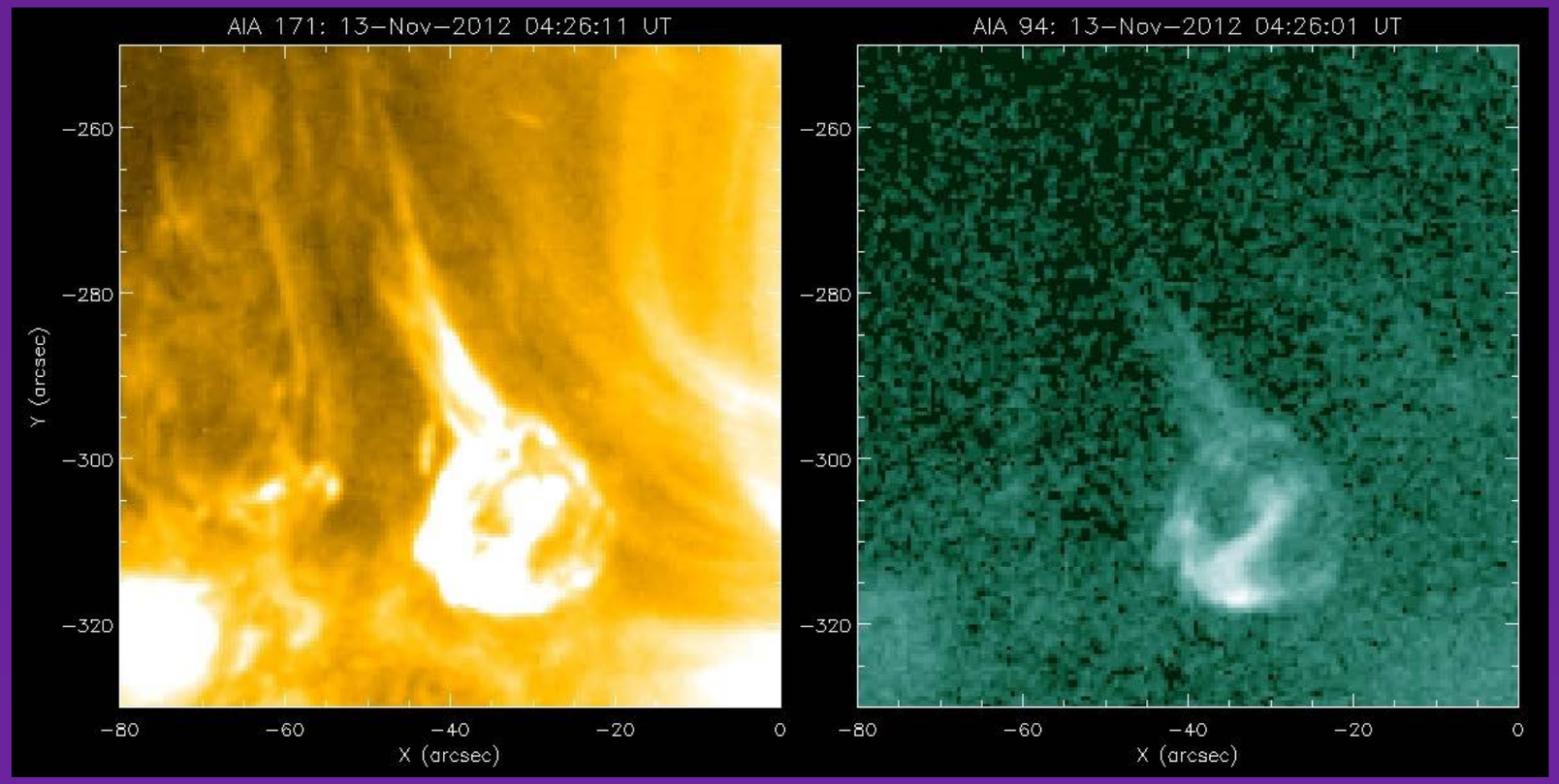
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AIA 94: 13-Nov-2012 04:26:01 UT
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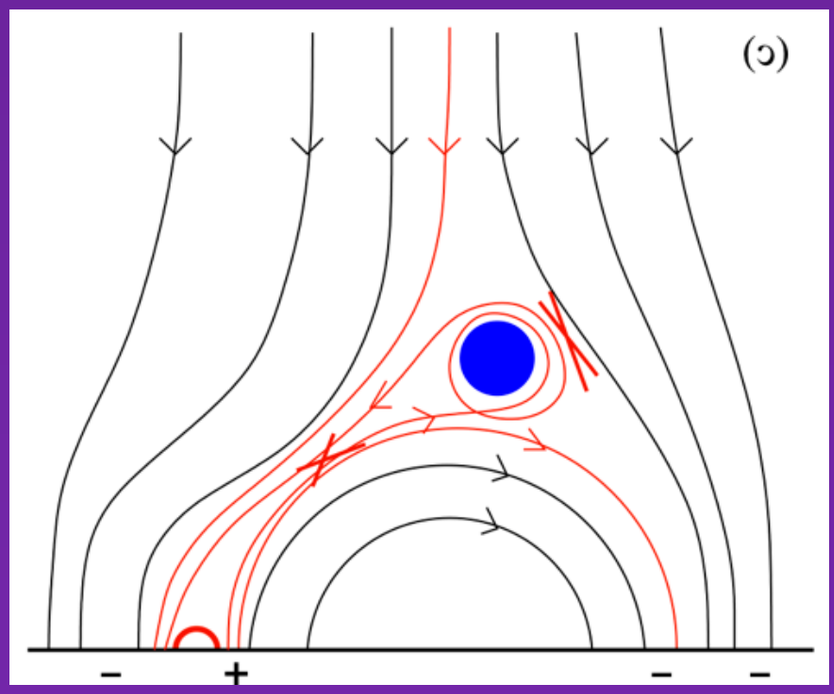
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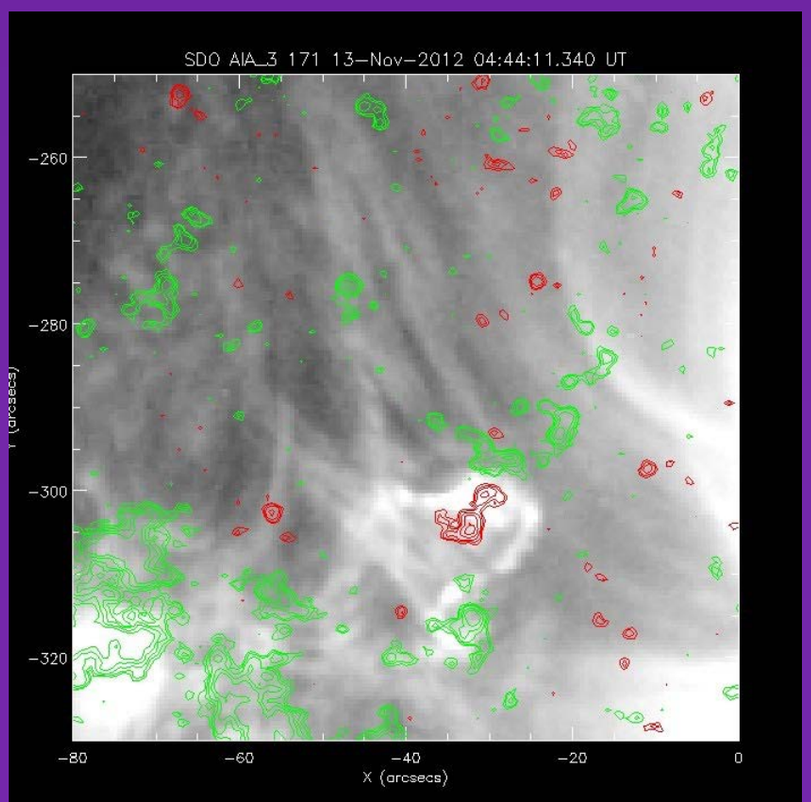
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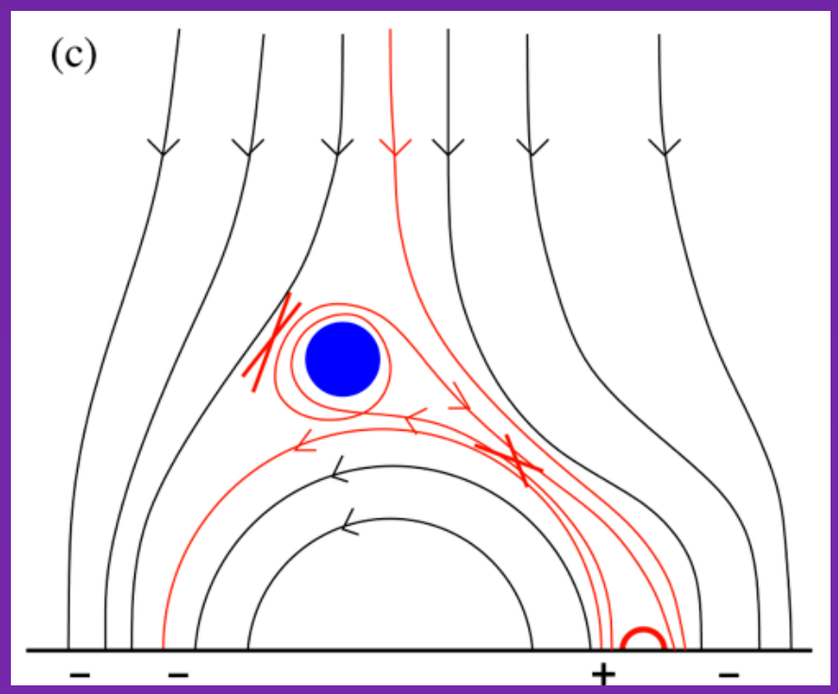
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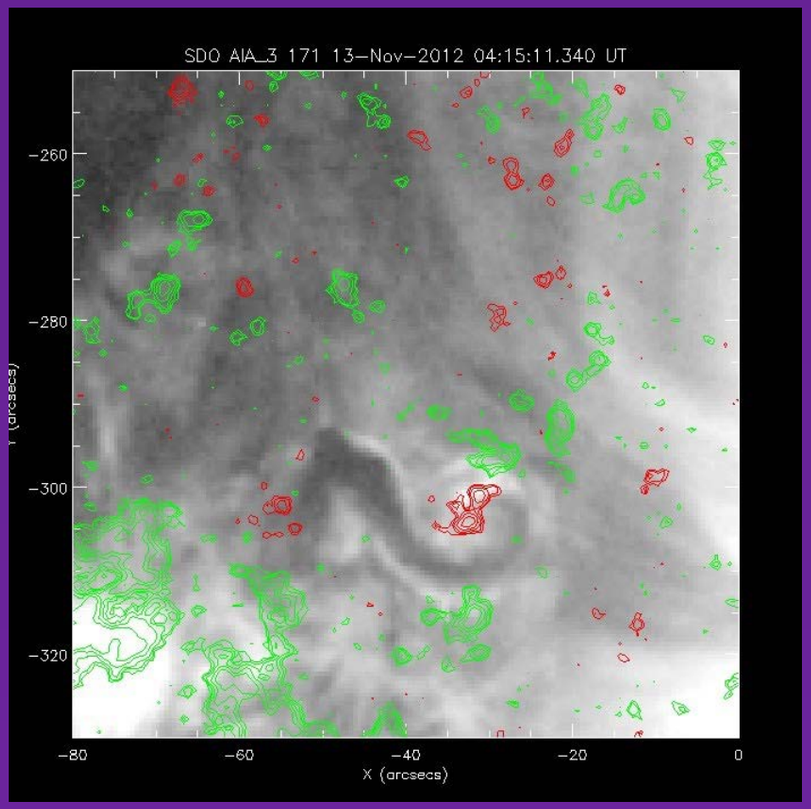
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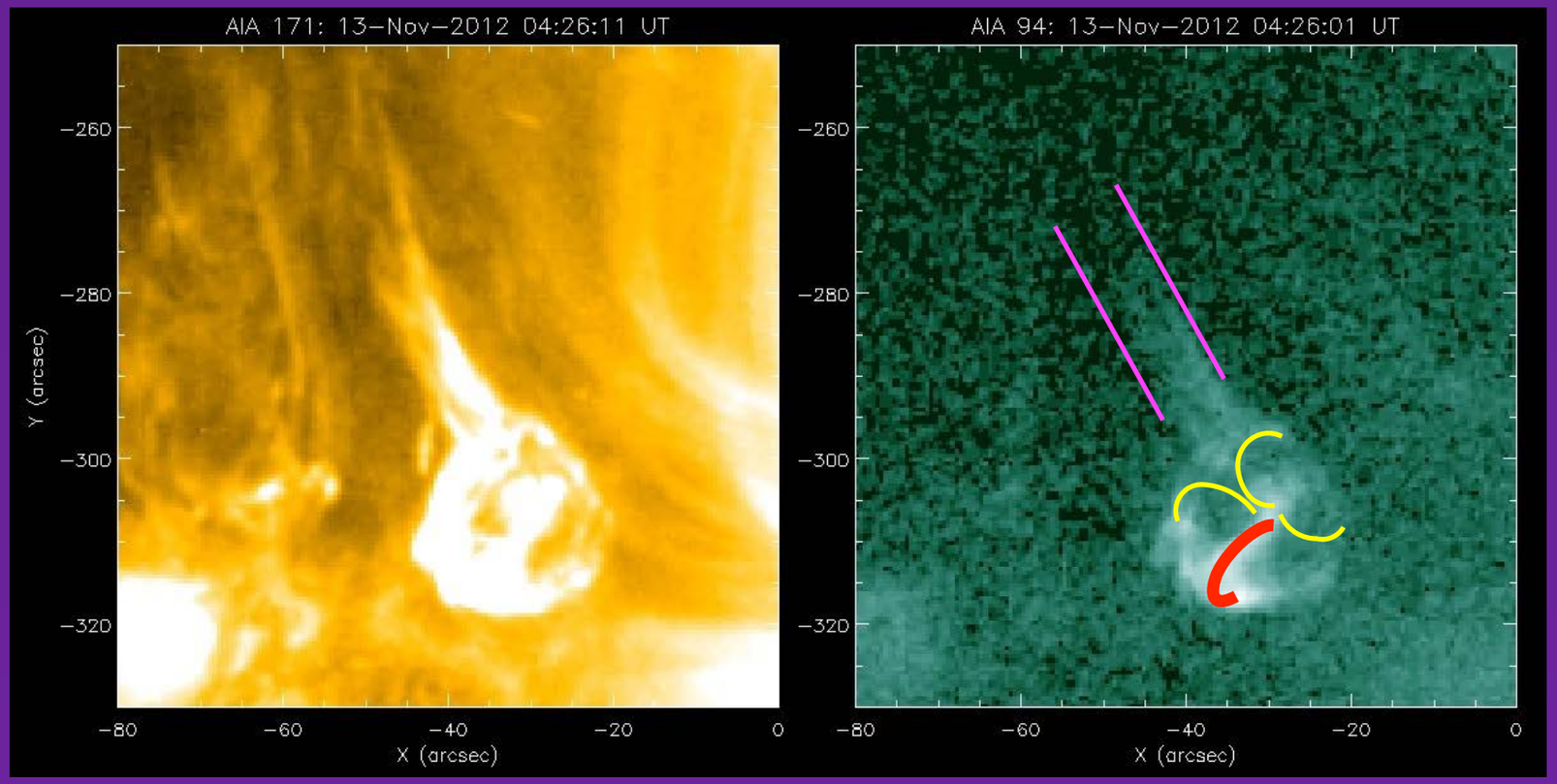
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AIA 94: 13-Nov-2012 04:26:01 UT
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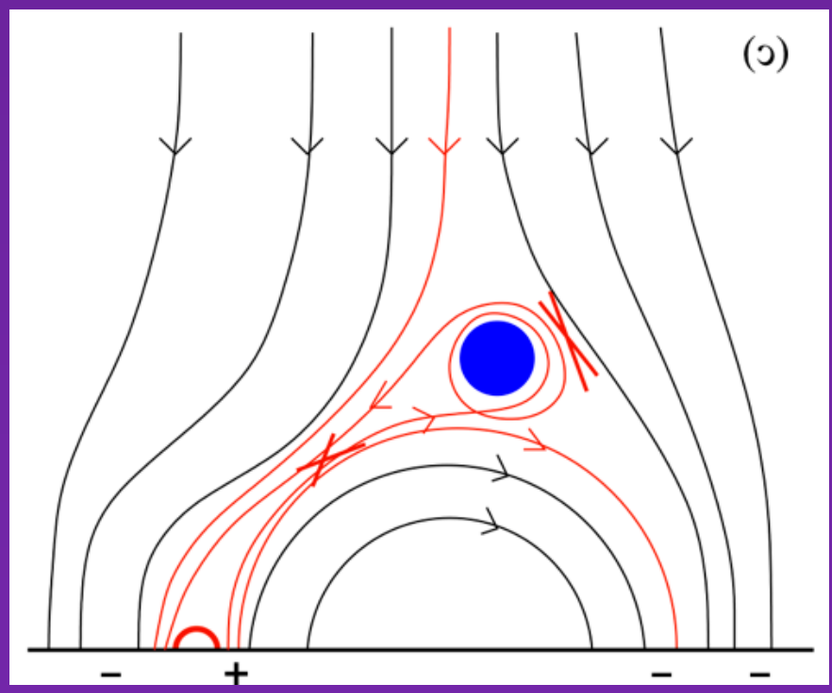
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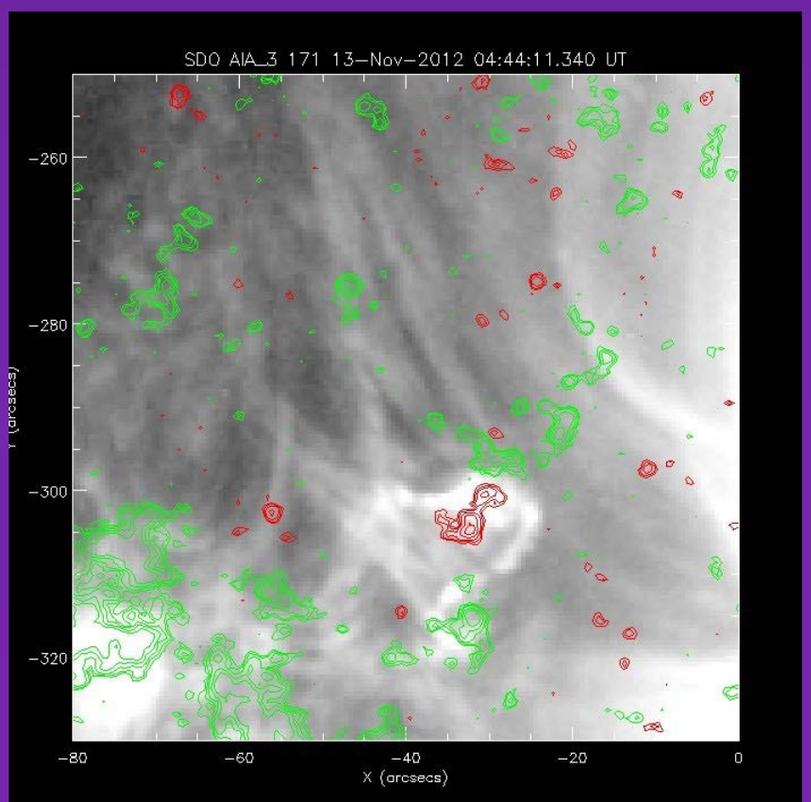
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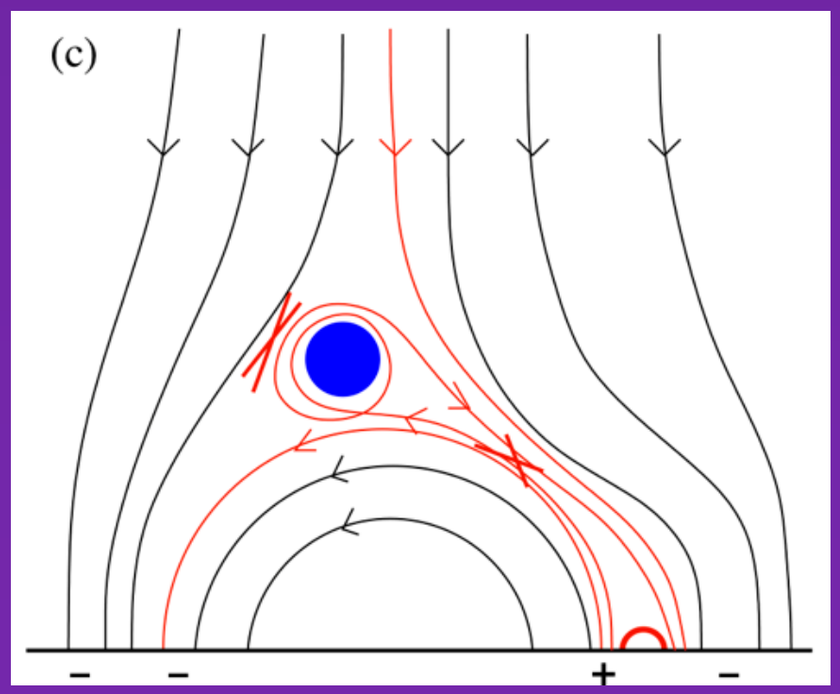
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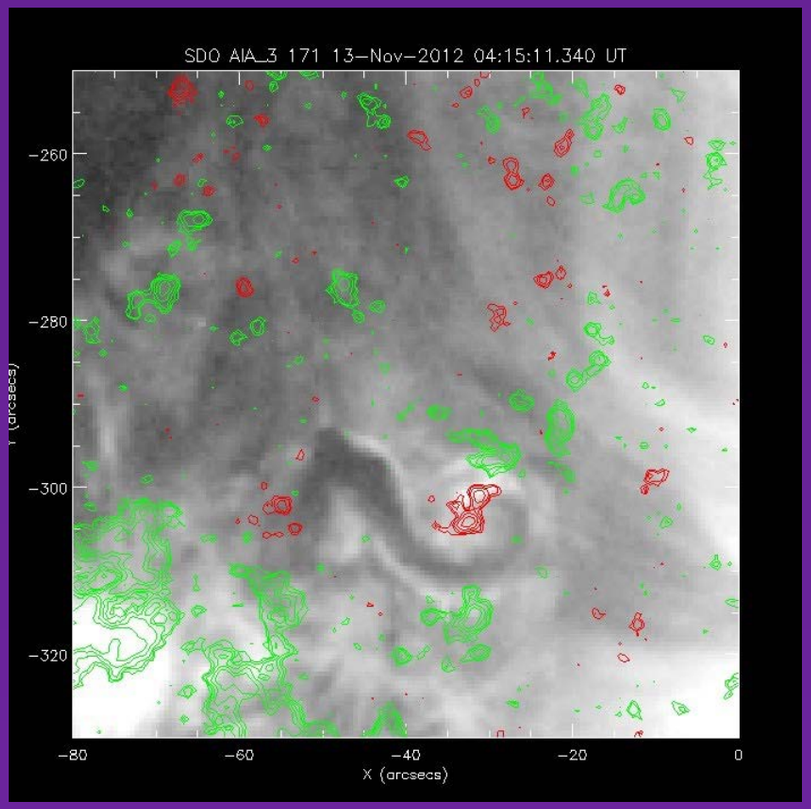
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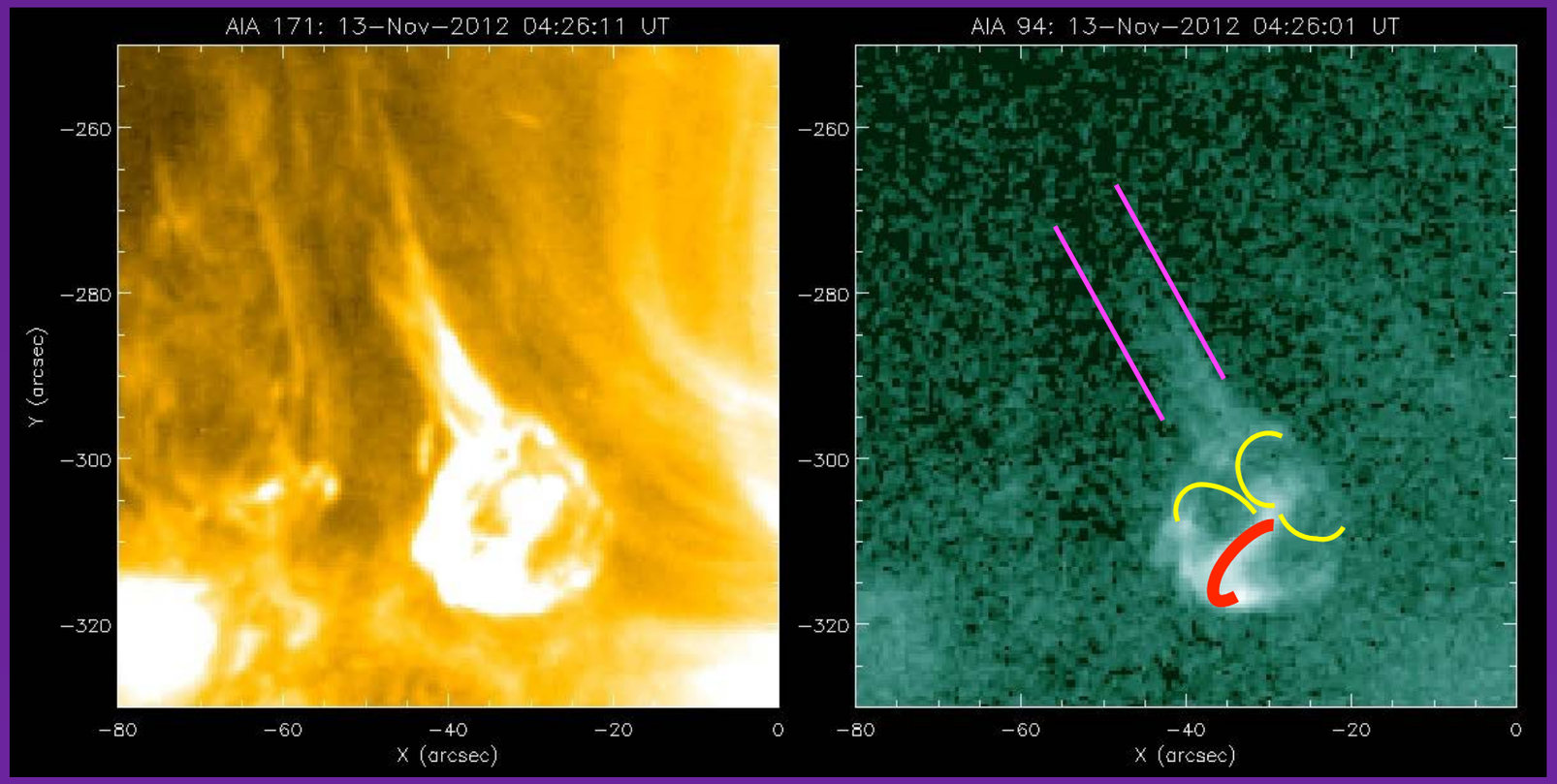
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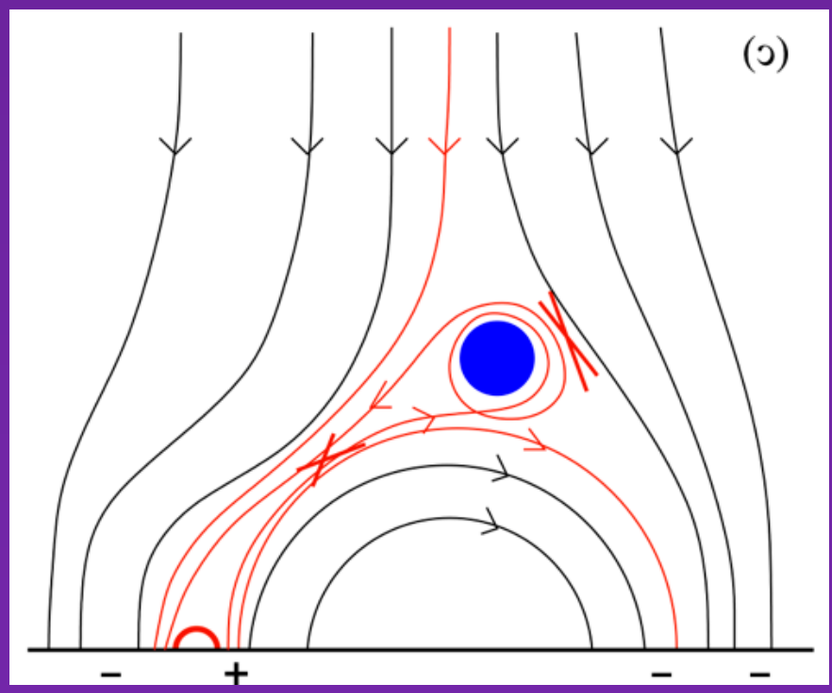
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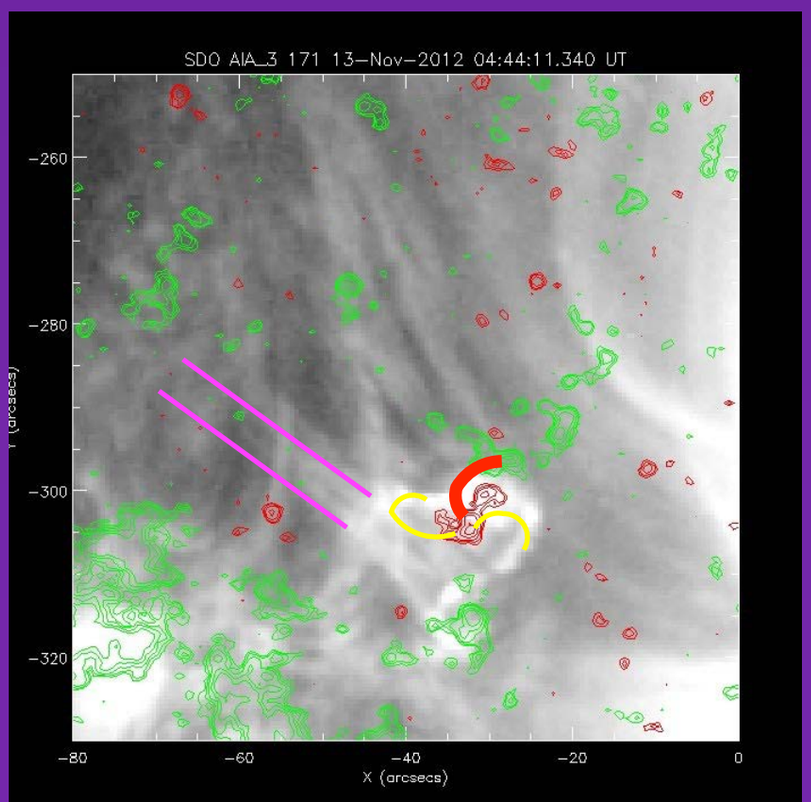
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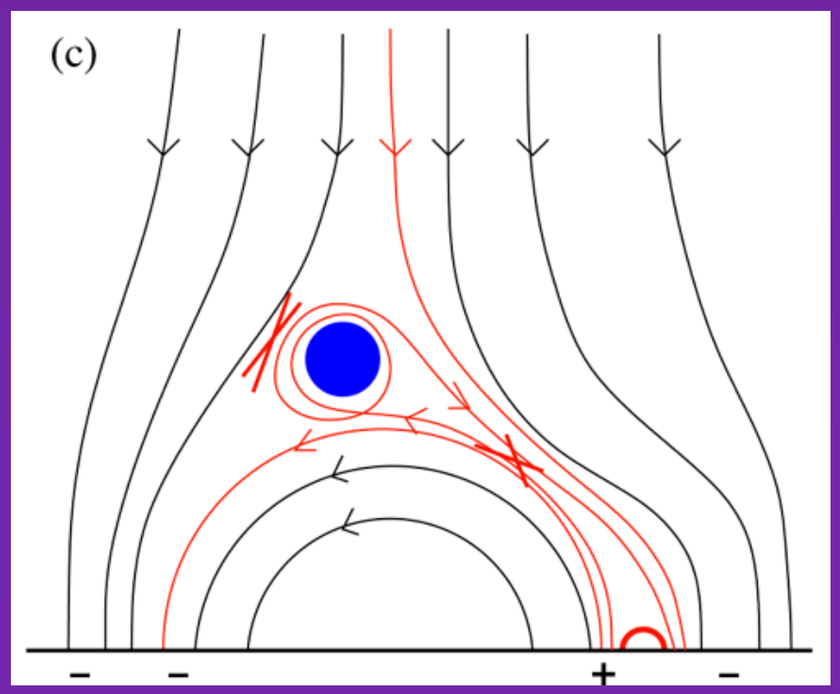
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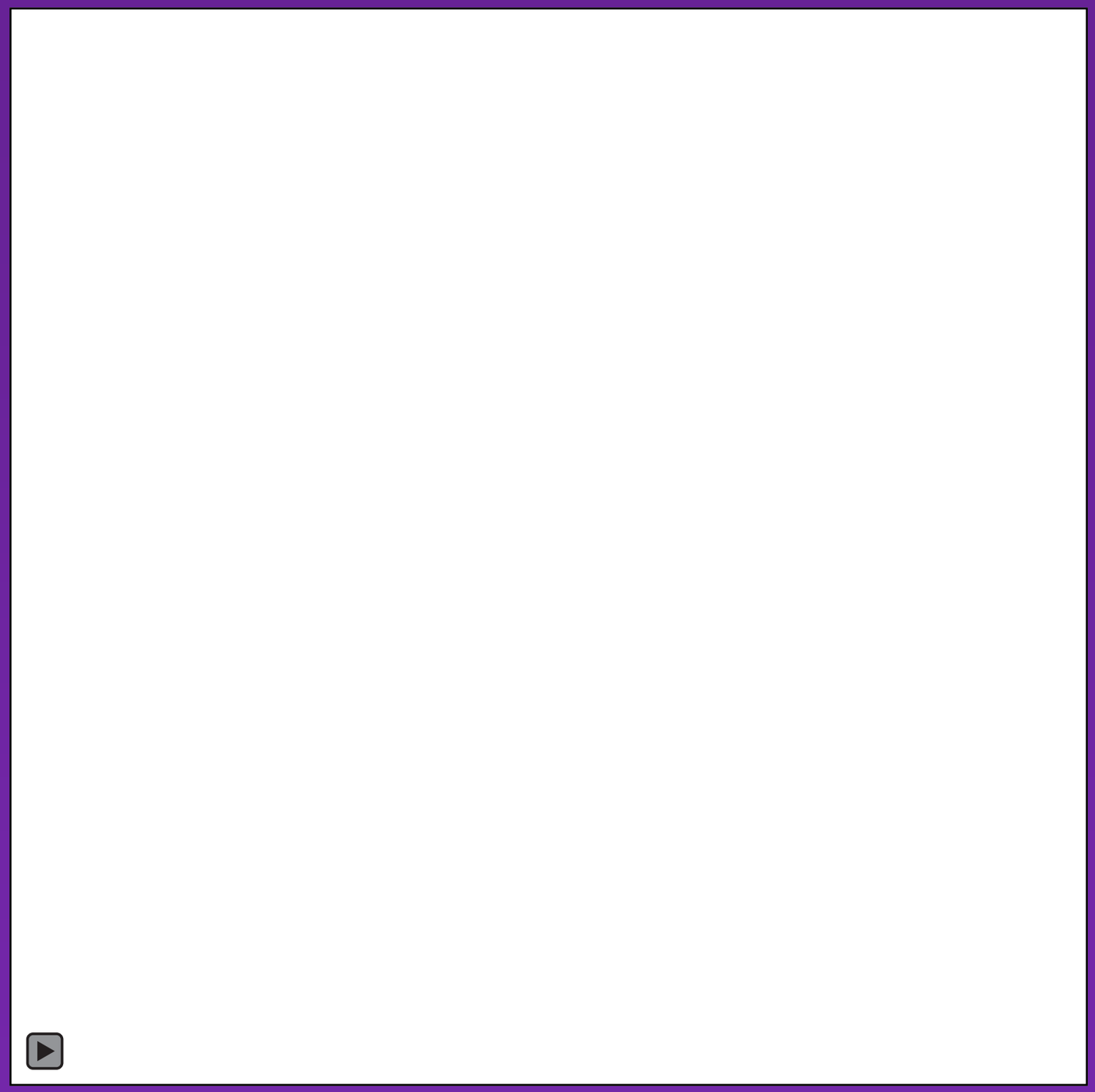


Panesar et al. (2016)

Observational AR Jet Studies — Many of them!

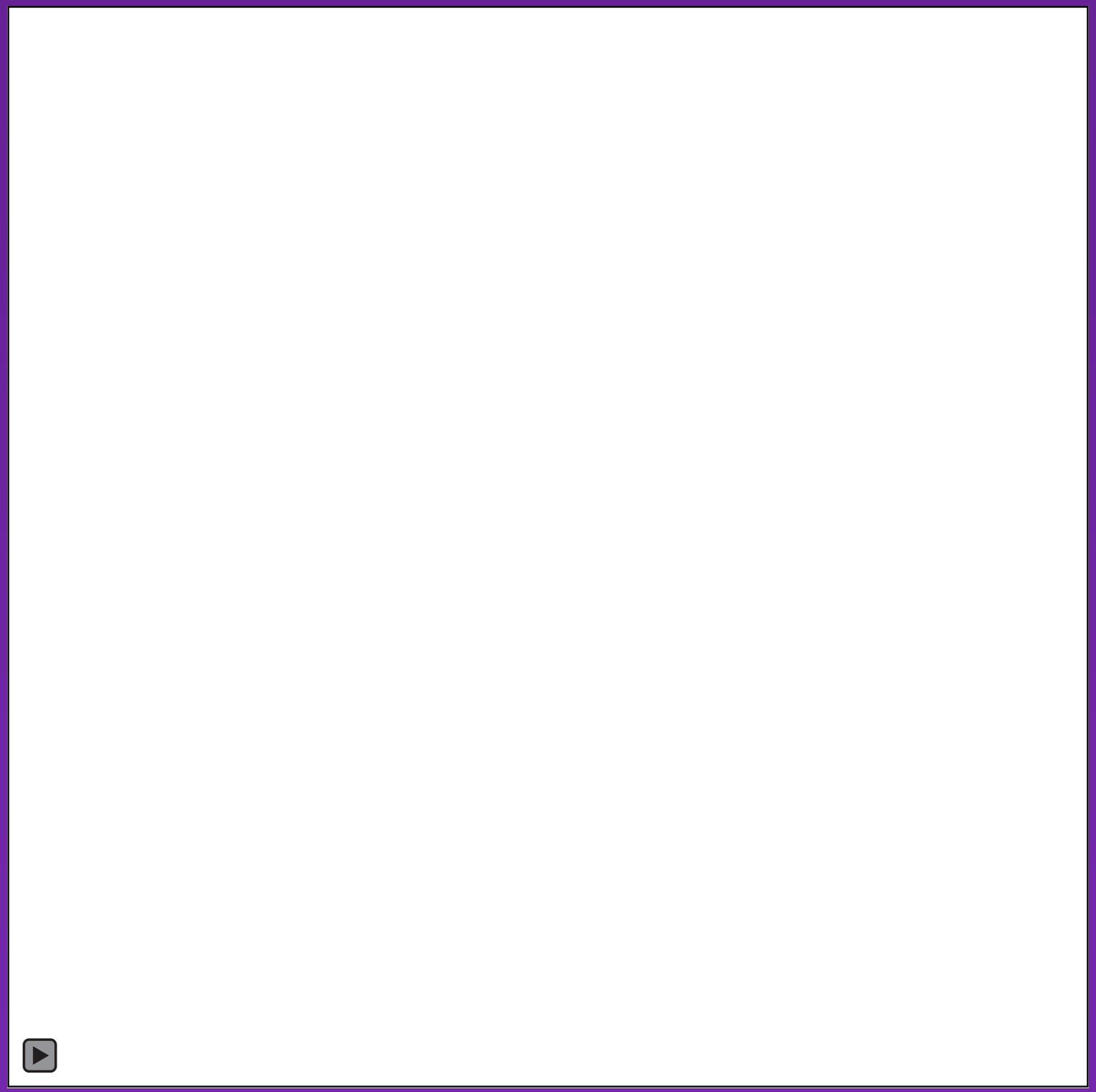
- Zhang et al. 2016: Circular ribbon flare+jet from filament eruption.
- Alzate & Morgan 2016: AR jets and “streamer puffs.”
- Mulay et al. 2016: 20 edge-of-AR jets.
- Zhang et al. 2016: Blobs from homologous jets in closed loop.
- Lim et al. 2016: Twisted morphology, flux emergence.
- Liu et al. 2016: Coronal jet triggering a CME.
- Panesar et al. 2016a: In this talk.
- Sterling et al. 2016: In this talk.
- Shelton, Harra, & Green 2015: AR jets from emerging “serpentine” field.
- Louis et al. 2015: Jets from flux emergence in AR complex.
- Etc. ...

- Coronal jets are also common ***in active regions***.
- Do they also originate from minifilament eruptions?
- We address here with AIA and HMI observations of jets in our first active region. (Hinode was observing elsewhere for this one.) Sterling et al. (2016, ApJ)

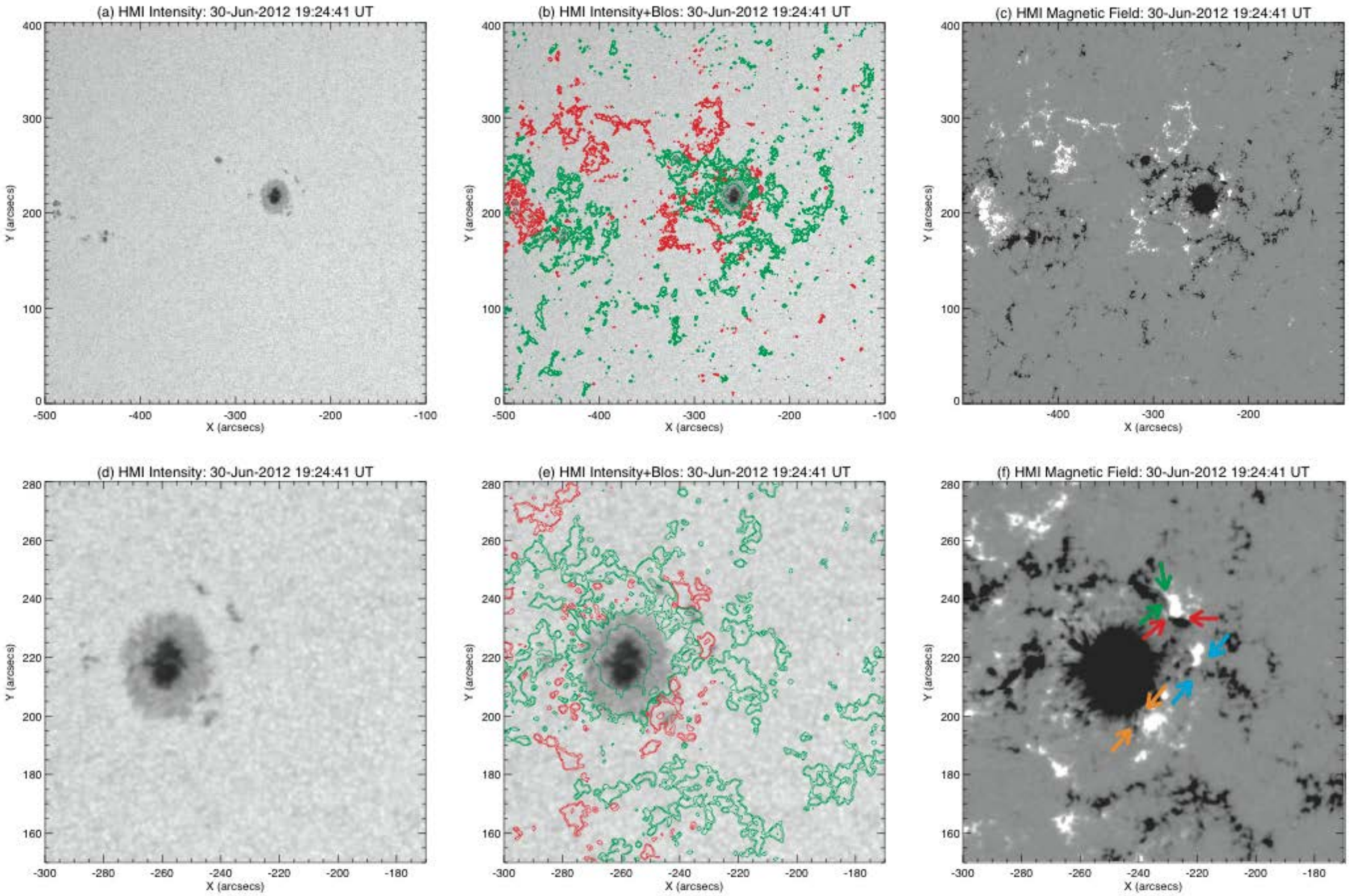
Active Region Jets Study

- Sterling et al. (2016), ApJ
- Single AR, AR 11513
- Only ~8-hr period, but many jets.
- AIA+HMI; no Hinode, but some SXI images.

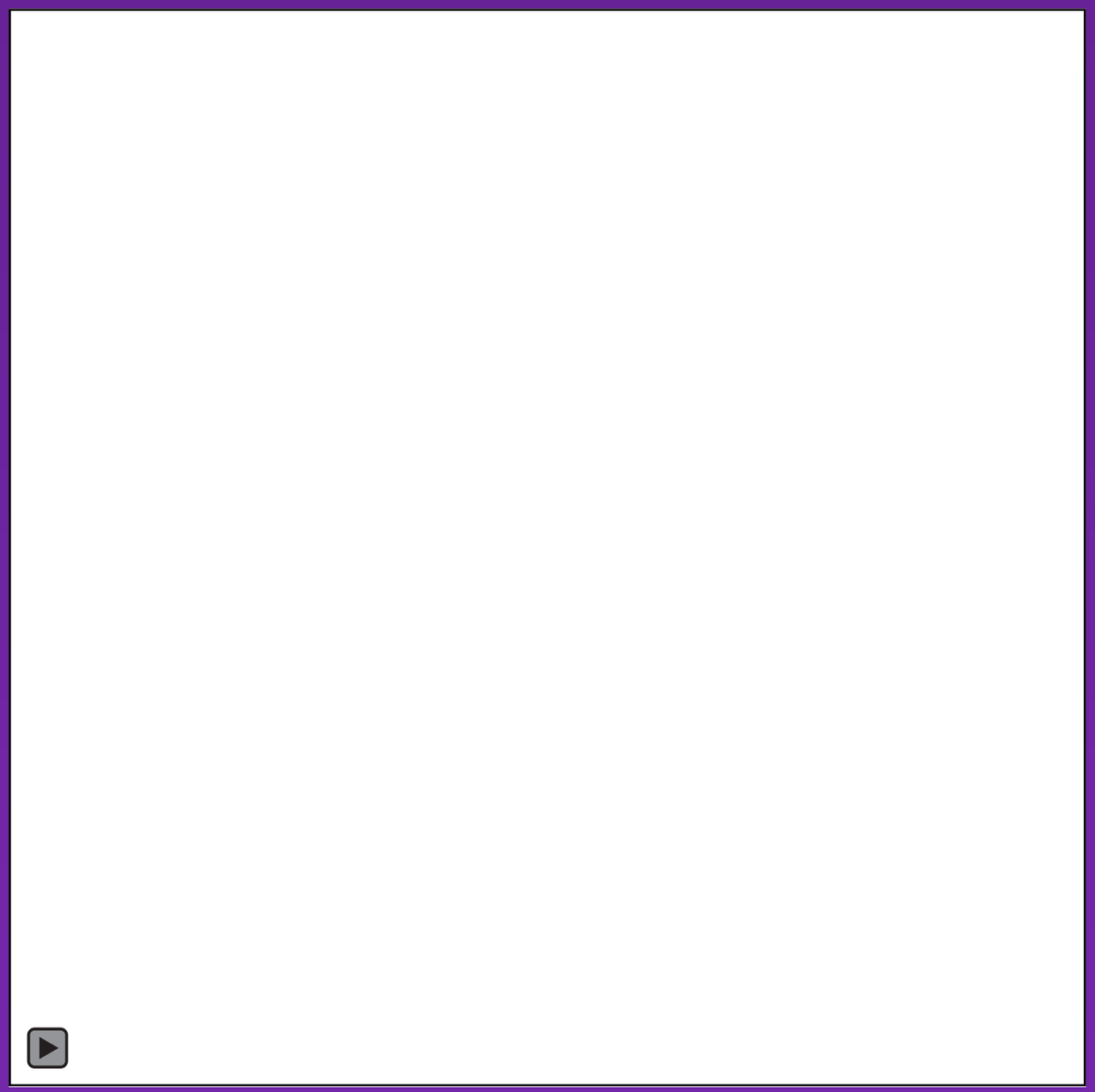
AIA 171



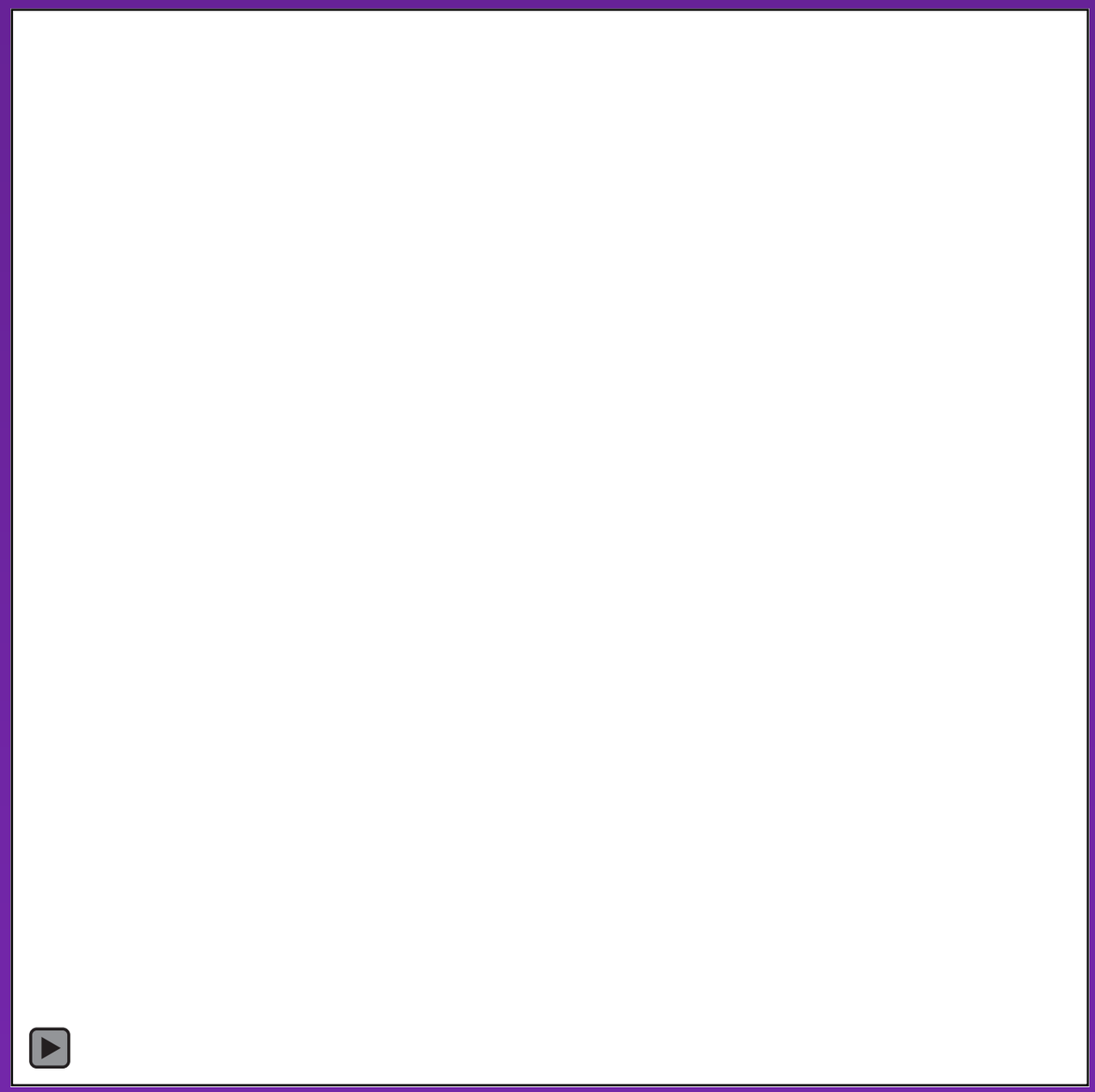
Sterling et al. (2016, ApJ)


(a) HMI Intensity: 30-Jun-2012 19:24:41 UT
(b) HMI Intensity+Blos: 30-Jun-2012 19:24:41 UT
(c) HMI Magnetic Field: 30-Jun-2012 19:24:41 UT
(d) HMI Intensity: 30-Jun-2012 19:24:41 UT
(e) HMI Intensity+Blos: 30-Jun-2012 19:24:41 UT
(f) HMI Magnetic Field: 30-Jun-2012 19:24:41 UT
Y (arcsecs)
X (arcsecs)

A. Sterling



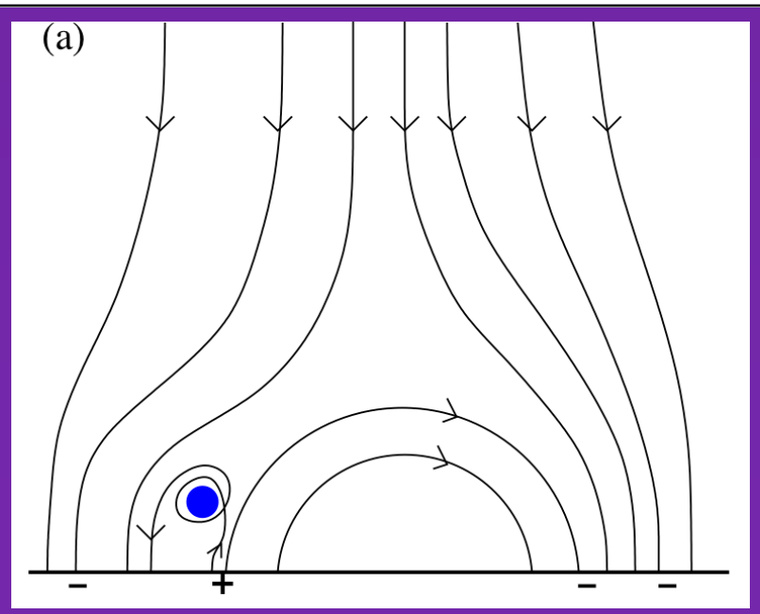
AIA 304



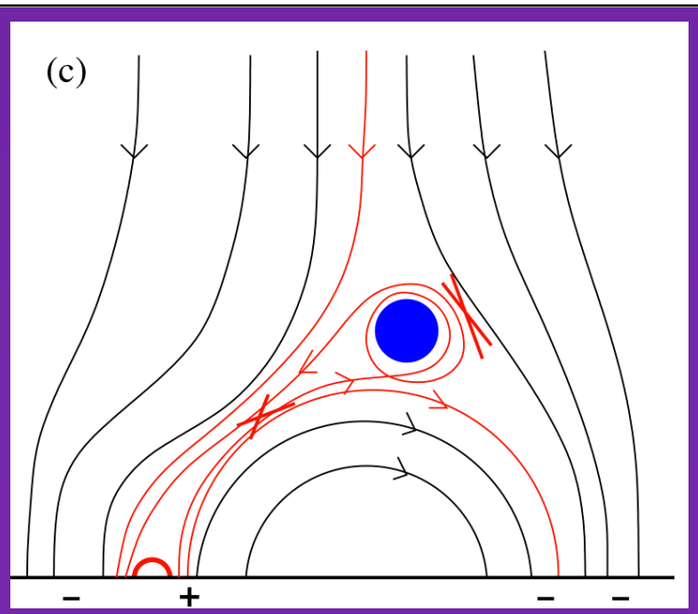
AIA 94

A. Sterling

AIA 304

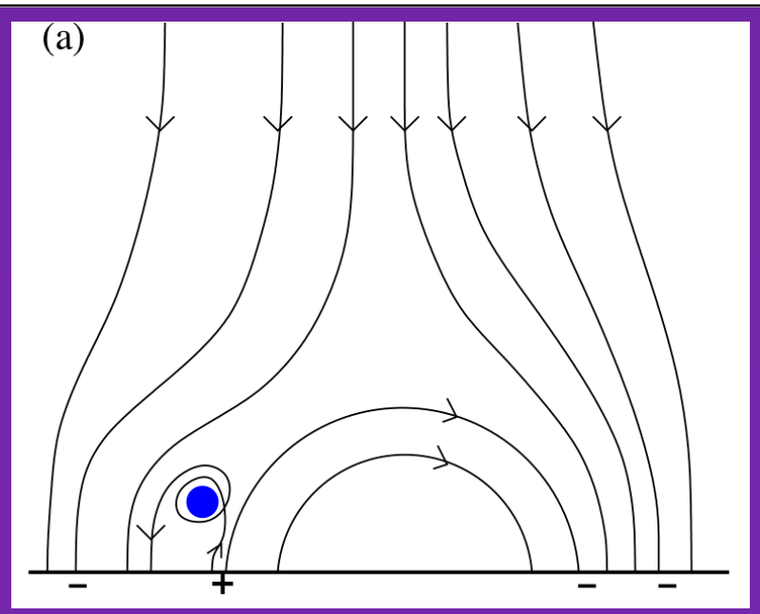


AIA 94

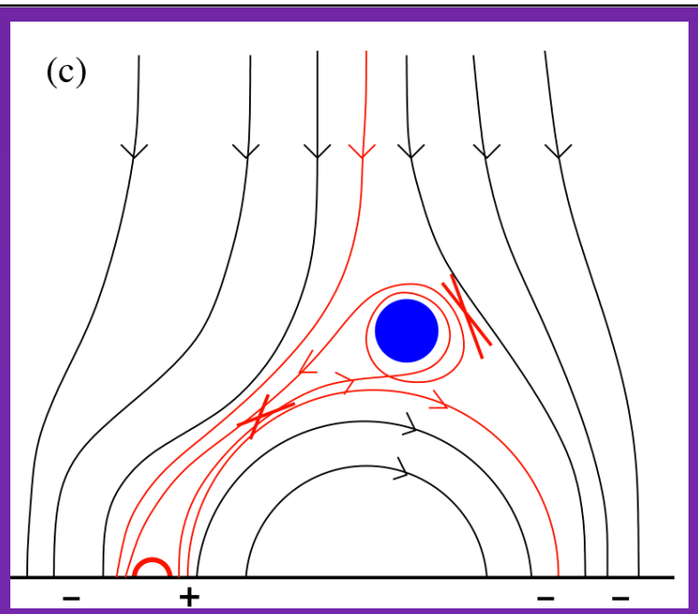


A. Sterling

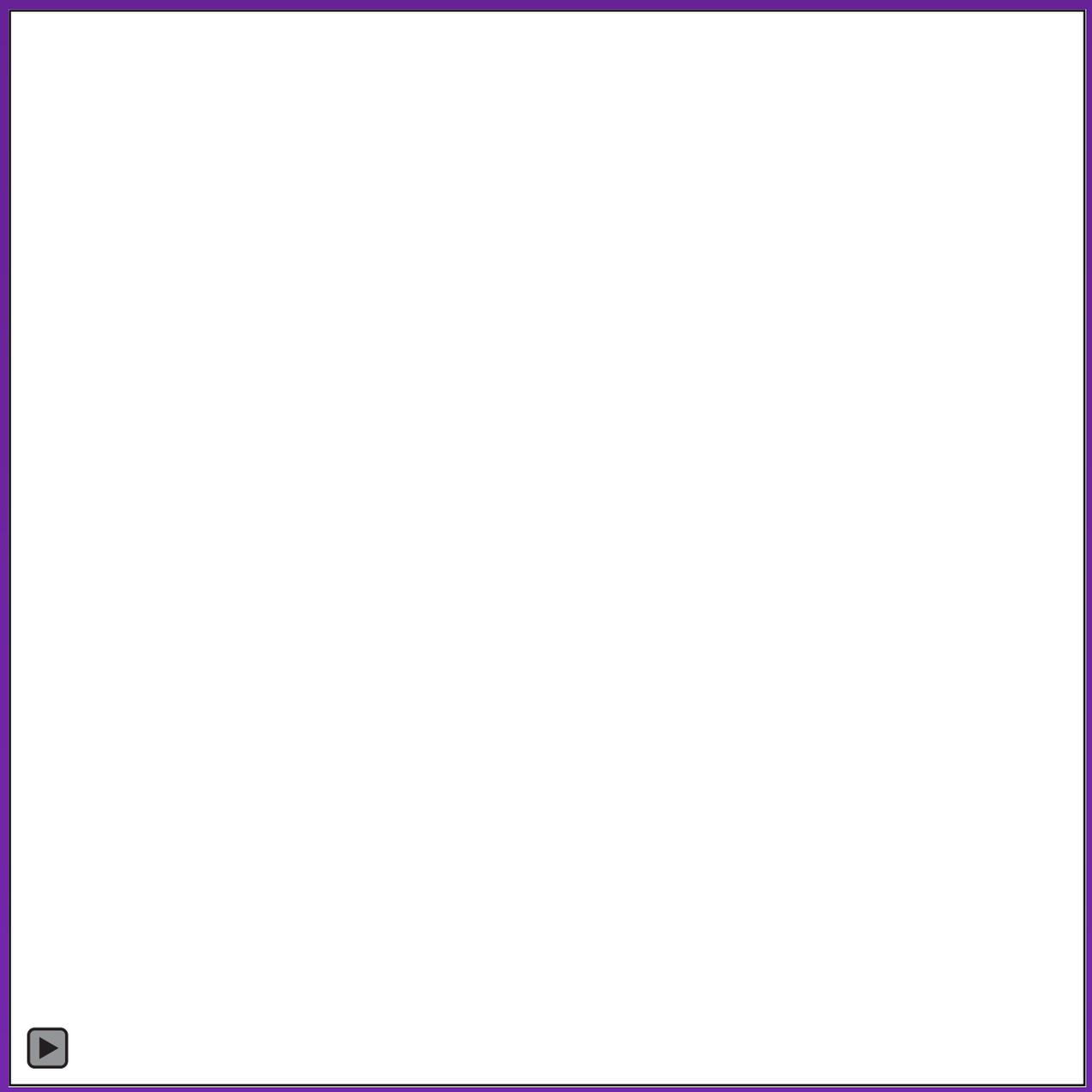
AIA 304



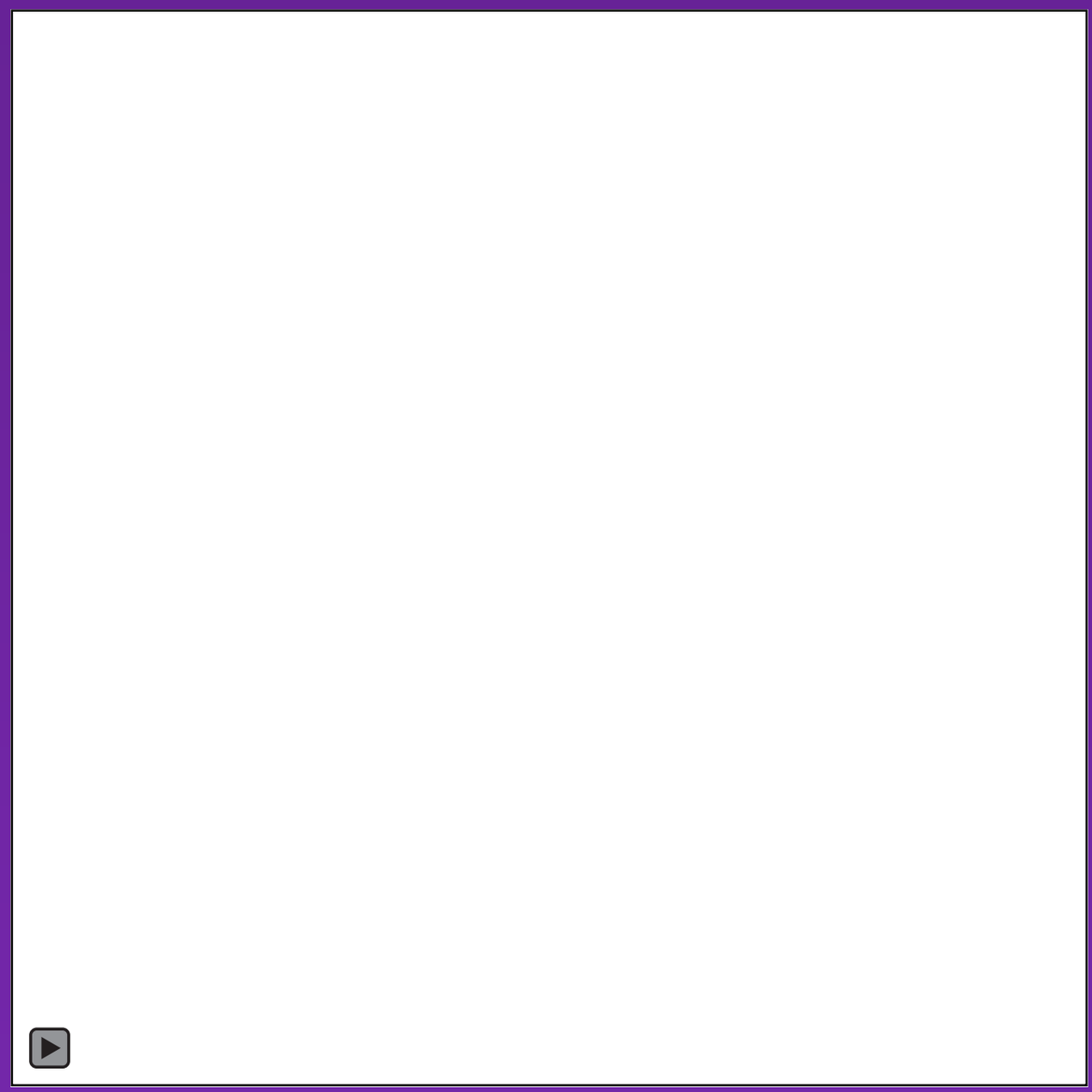
AIA 94



A. Sterling

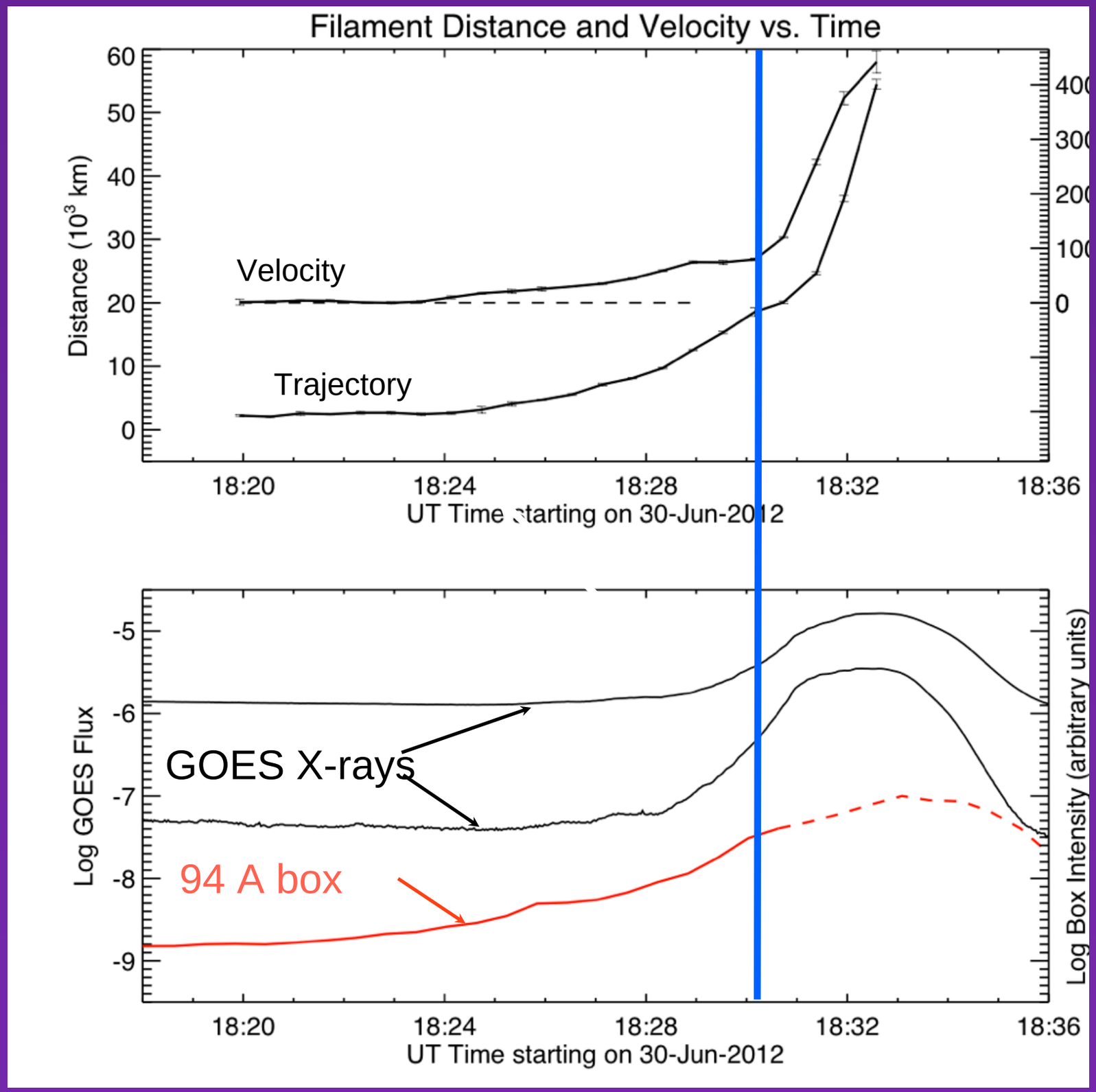


AIA 304



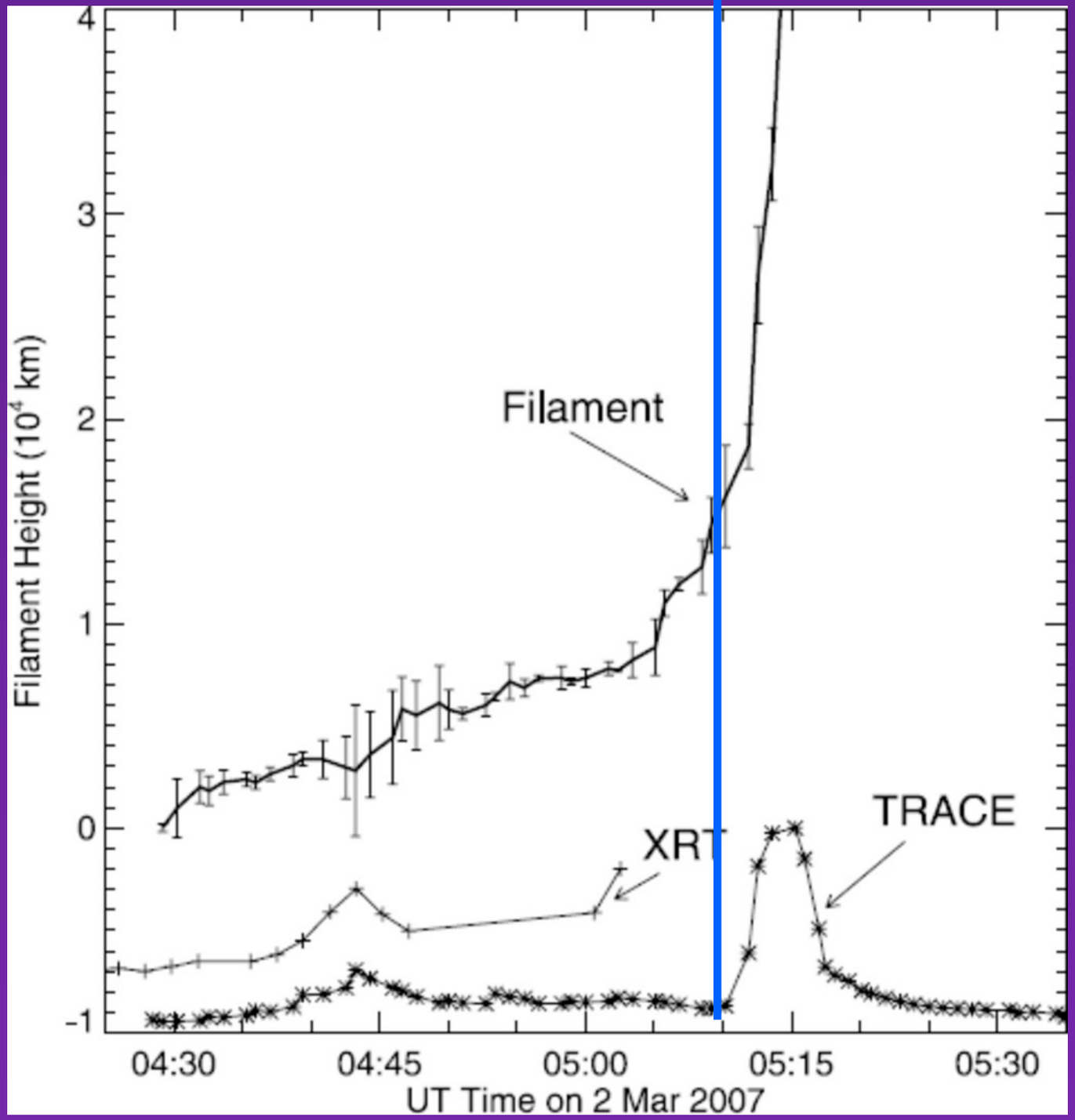
AIA 94

A. Sterling


Filament Distance and Velocity vs. Time
Distance (10^3 km)
60
50
40
30
20
10
0
Velocity
Trajectory
18:20
18:24
18:28
18:32
18:36
UT Time starting on 30-Jun-2012
Log GOES Flux
-5
-6
-7
-8
-9
GOES X-rays
94 A box
Log Box Intensity (arbitrary units)
18:20
18:24
18:28
18:32
18:36
UT Time starting on 30-Jun-2012

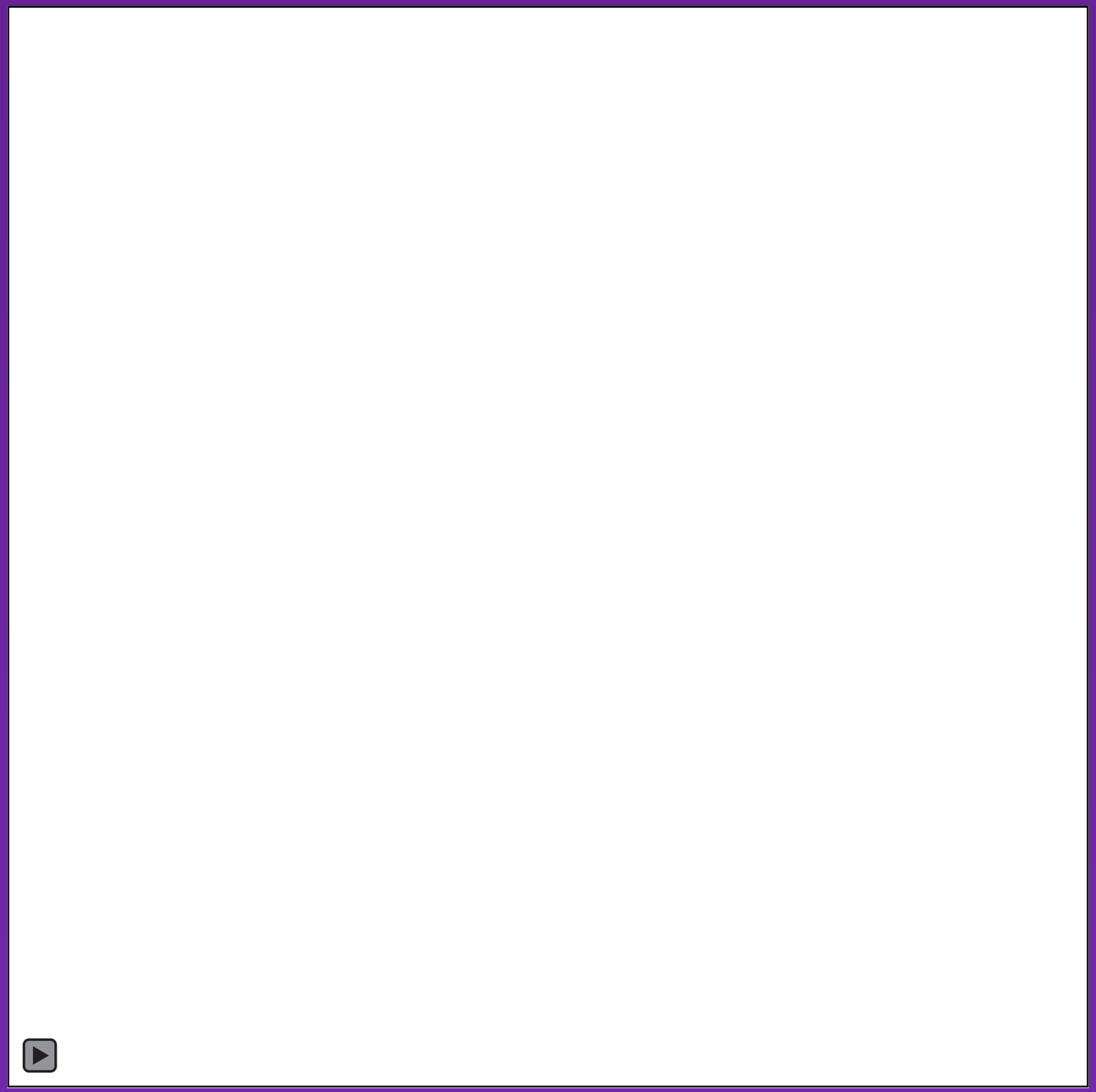
A. Sterling

“Normal” filament eruption+flare



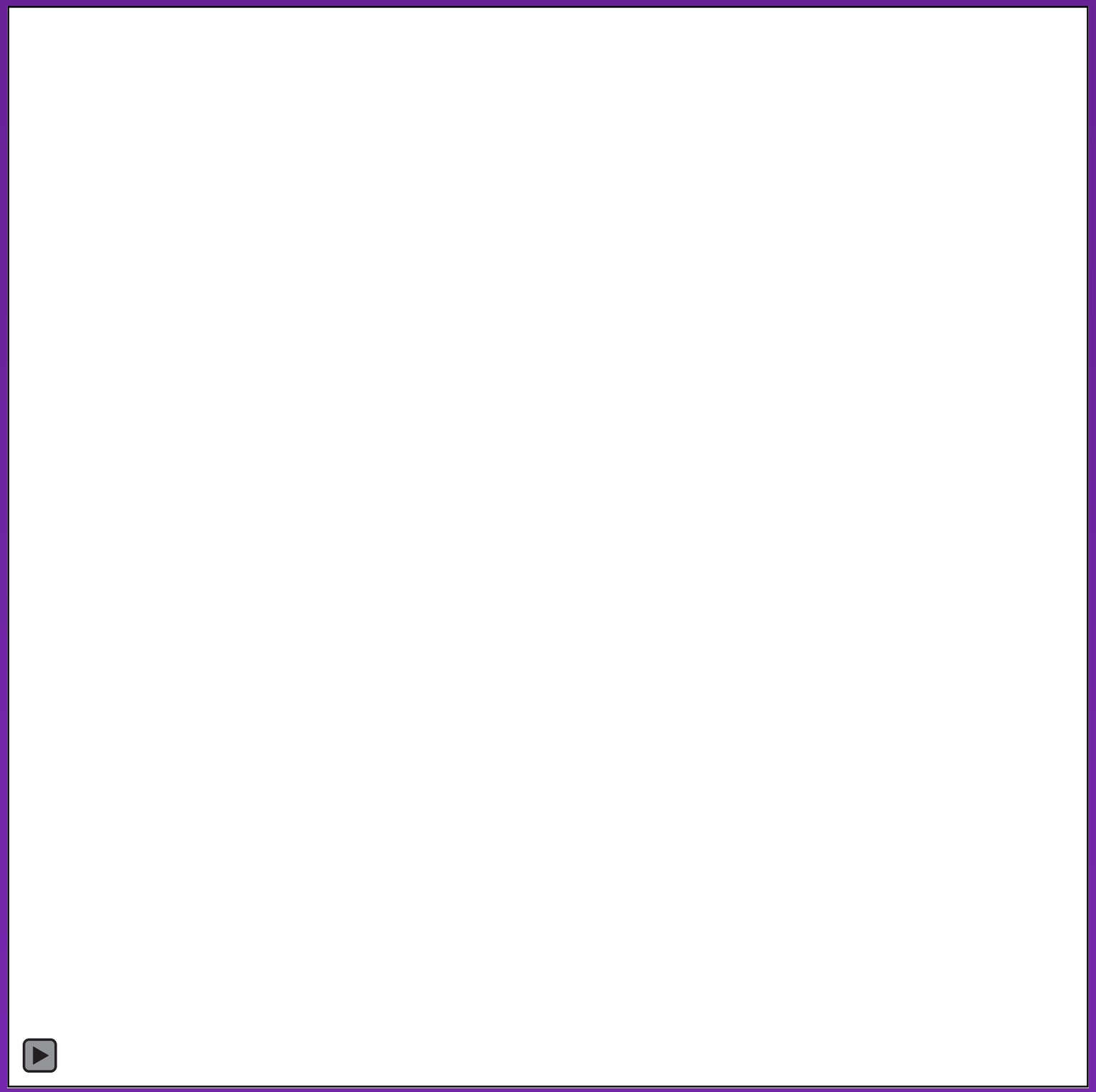
Sterling et al. (2007, PASJ)

AIA 171

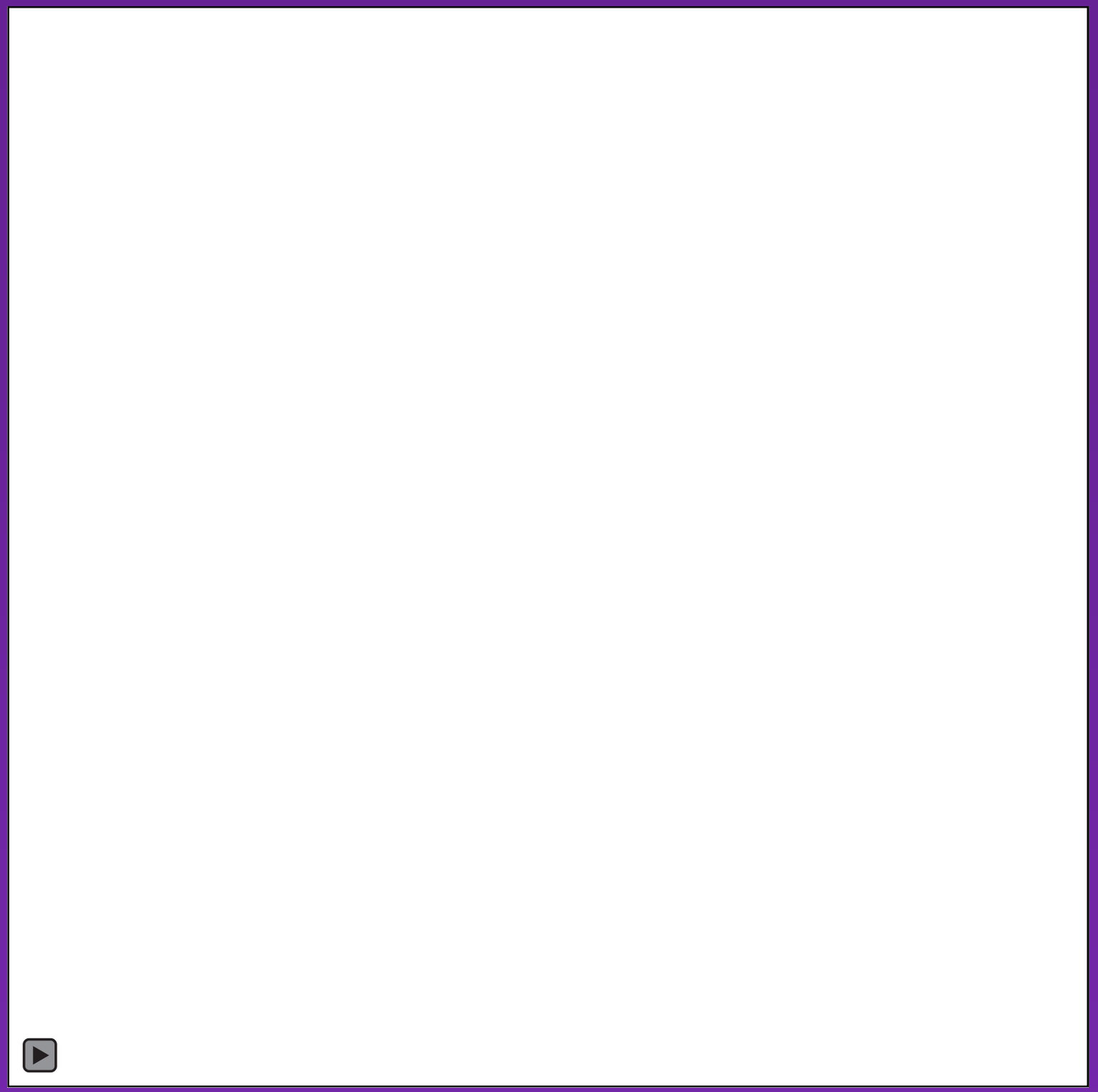


Sterling et al. (2016, ApJ)

AIA 304



A. Sterling



Minifilament eruptions (jets) often occur at flux-cancelation sites. Flux emergence may play a role in triggering eruptions. (Also, e.g., Kano et al. 2010; Hong et al. 2010; Shen et al. 2012;Young & Muglach 2014a, b; Chandrashekhar et al. 2014, Adams et al. 2014.)

So for these AR jets:

- Slower-buildup jets and faster-buildup jets
- Slower-buildup jets are surge and spray.

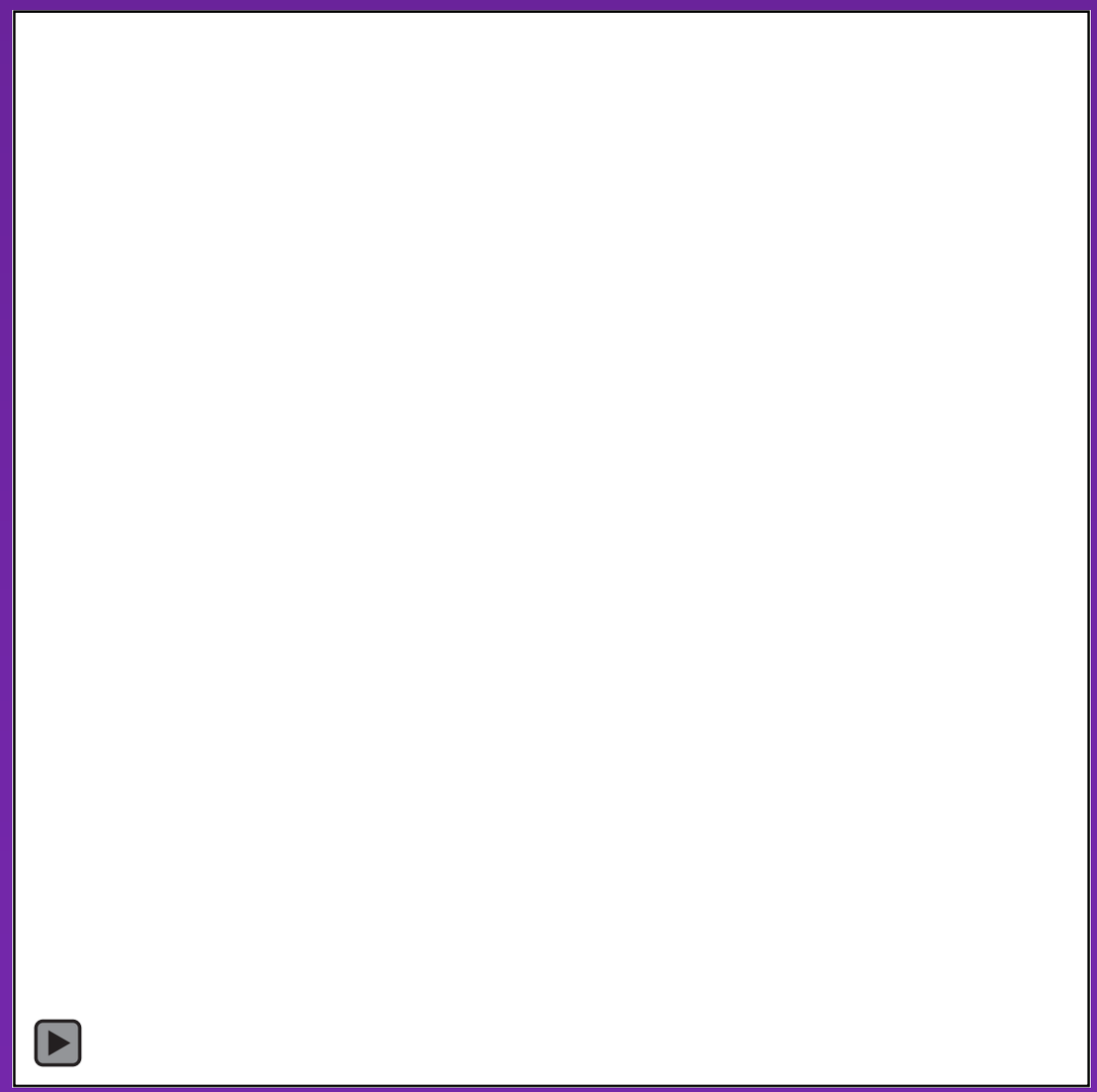
- Surge/spray look like minifilament-eruption scenario.
- As a corollary, they also look like ``normal'' filament-eruptions and flares.

- The faster-buildup jets are harder to sort out. Consistent with minifilament scenario. (Minifilaments may be very "thin"; cf. Schmieder et al. 2013.)

- All jets occur on neutral lines.
- Minifilament eruption/jet onset trigger: flux cancelation, flux cancelation+emergence, and maybe emerging flux alone (for minifilament-eruption trigger). (Cf. Mulay et al. 2016: 10, 6 and 4, respectively.)

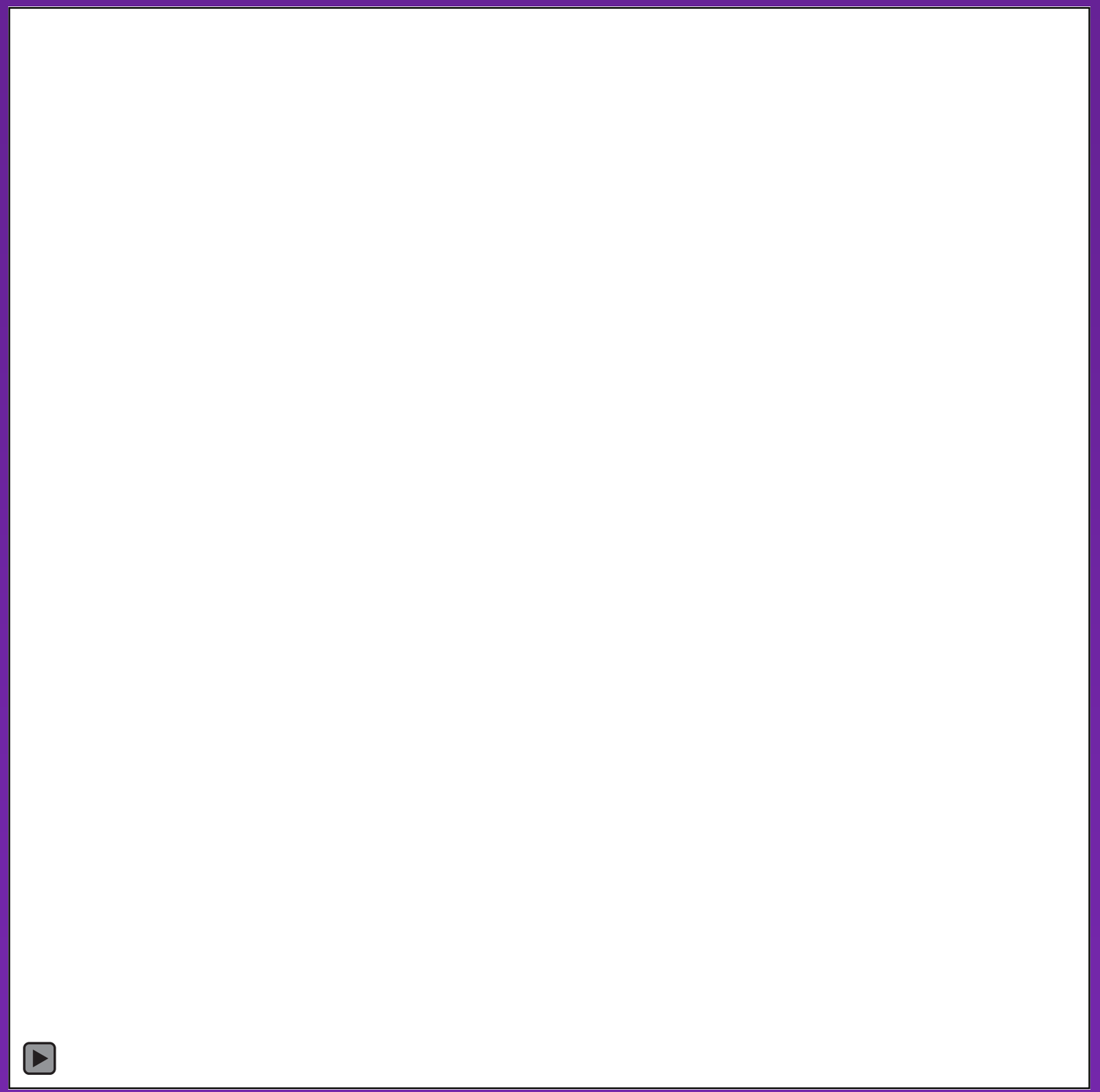
To investigate further, look at a different AR:

- 14 Jan 2015 (NOAA AR 12259).
- AIA, HMI, Hinode, IRIS
- (Assistance from Francisco Martinez, MSFC summer 2016 REU student.)



Hinode/XRT

AIA 193



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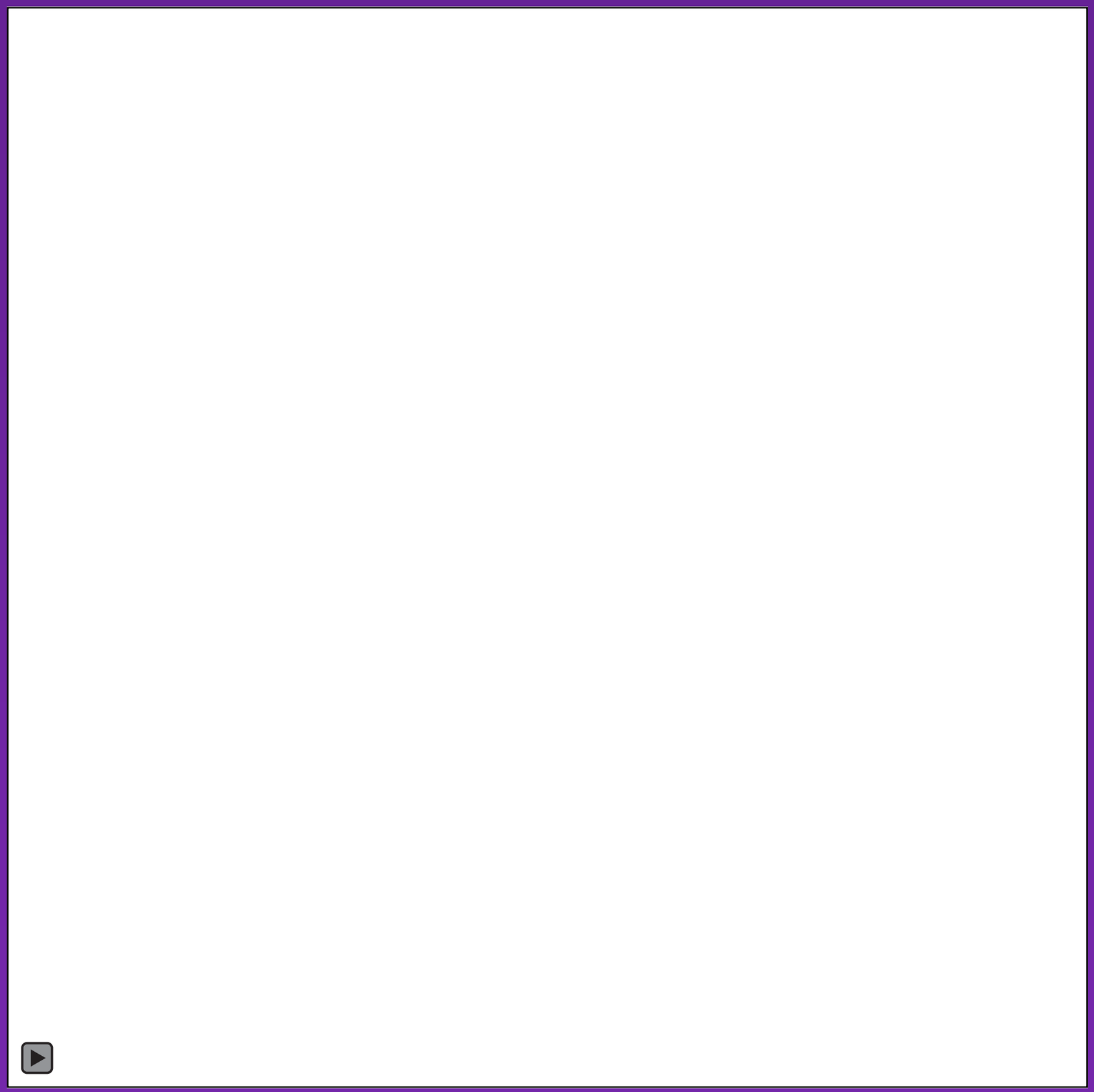
IRIS 1400



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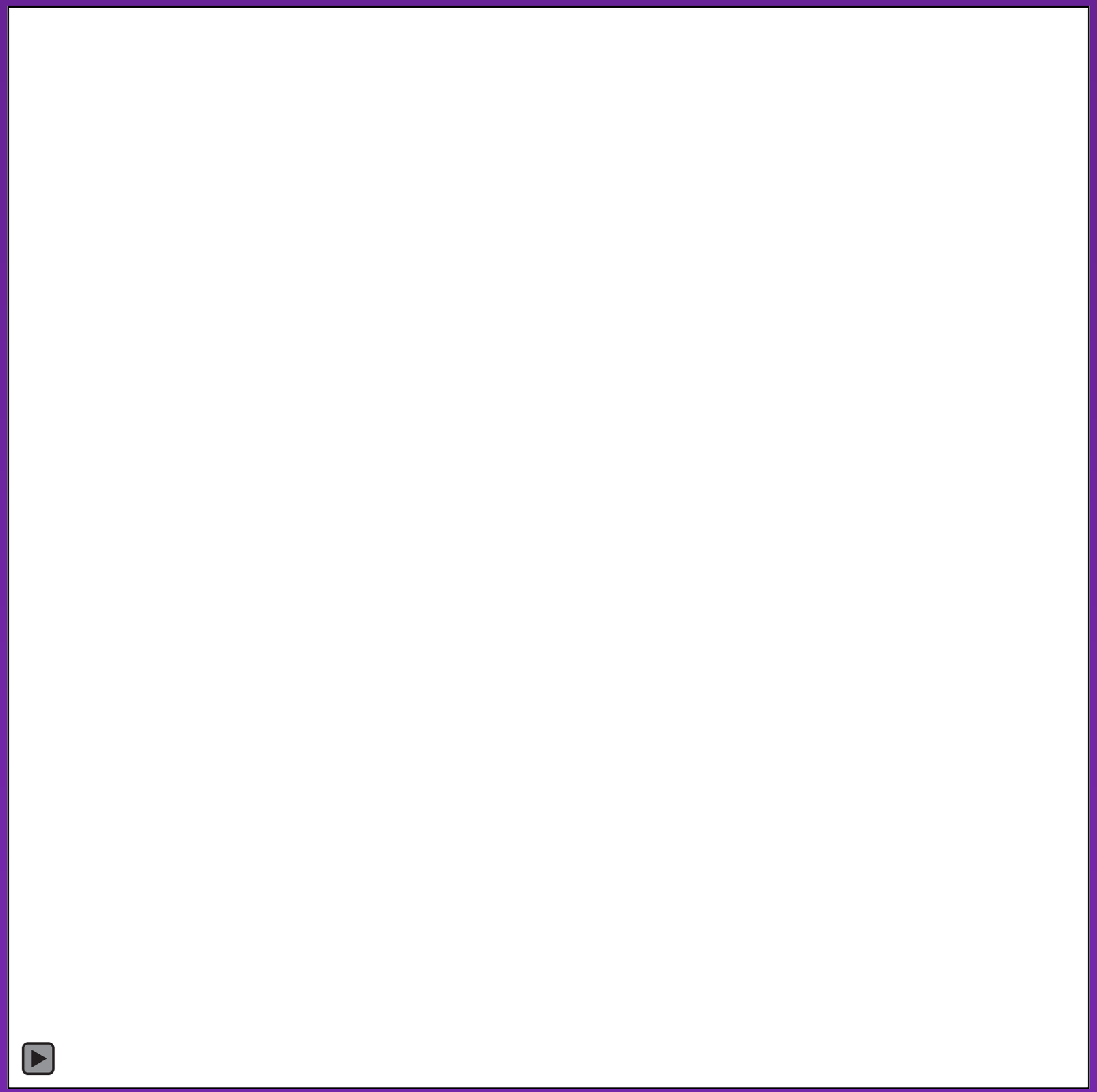
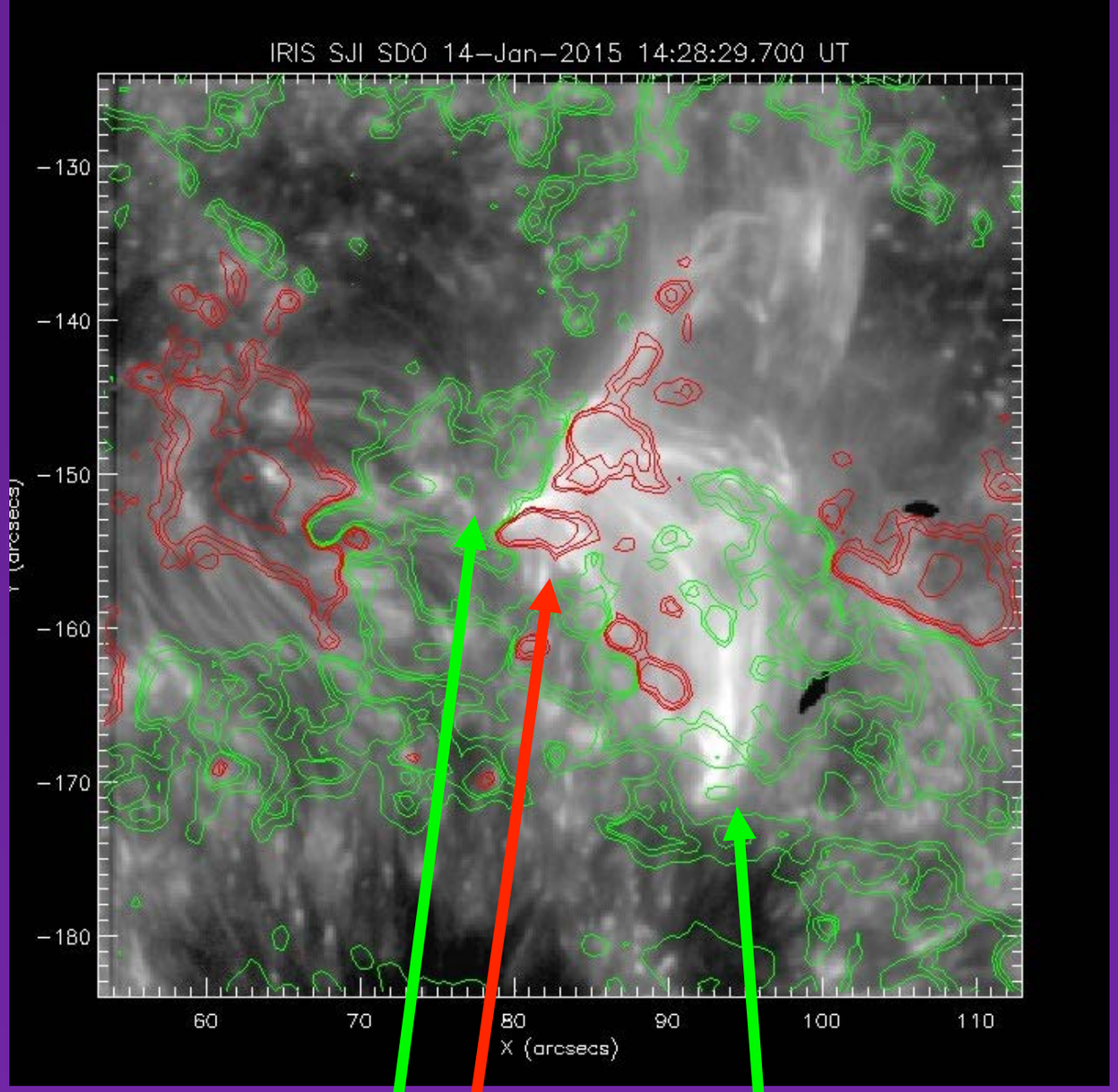
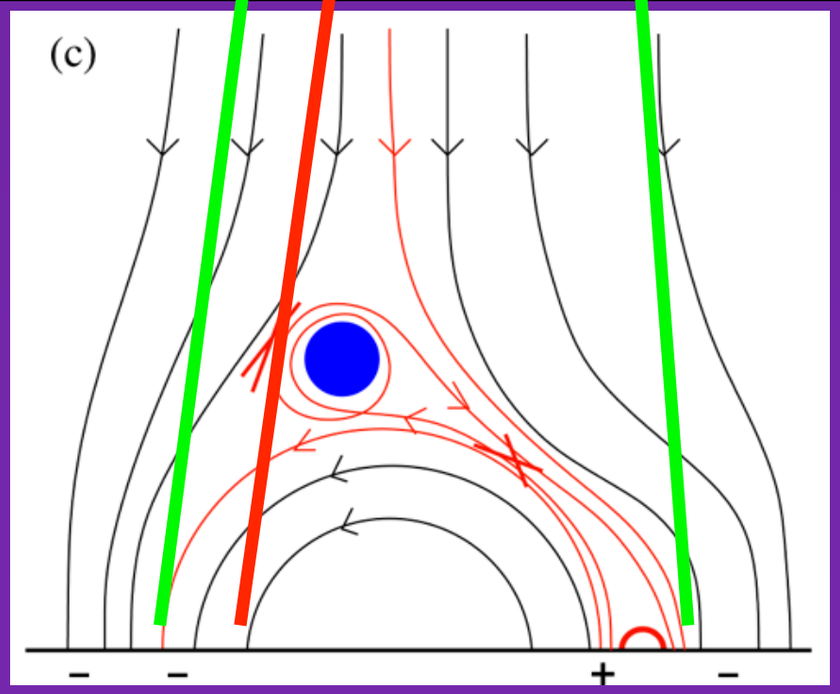
HMI on IRIS 1400




IRIS SJI SDO 14-Jan-2015 14:28:29.700 UT
-130
-140
-150
-160
-170
-180
Y (arcsecs)
60
70
80
90
100
110
X (arcsecs)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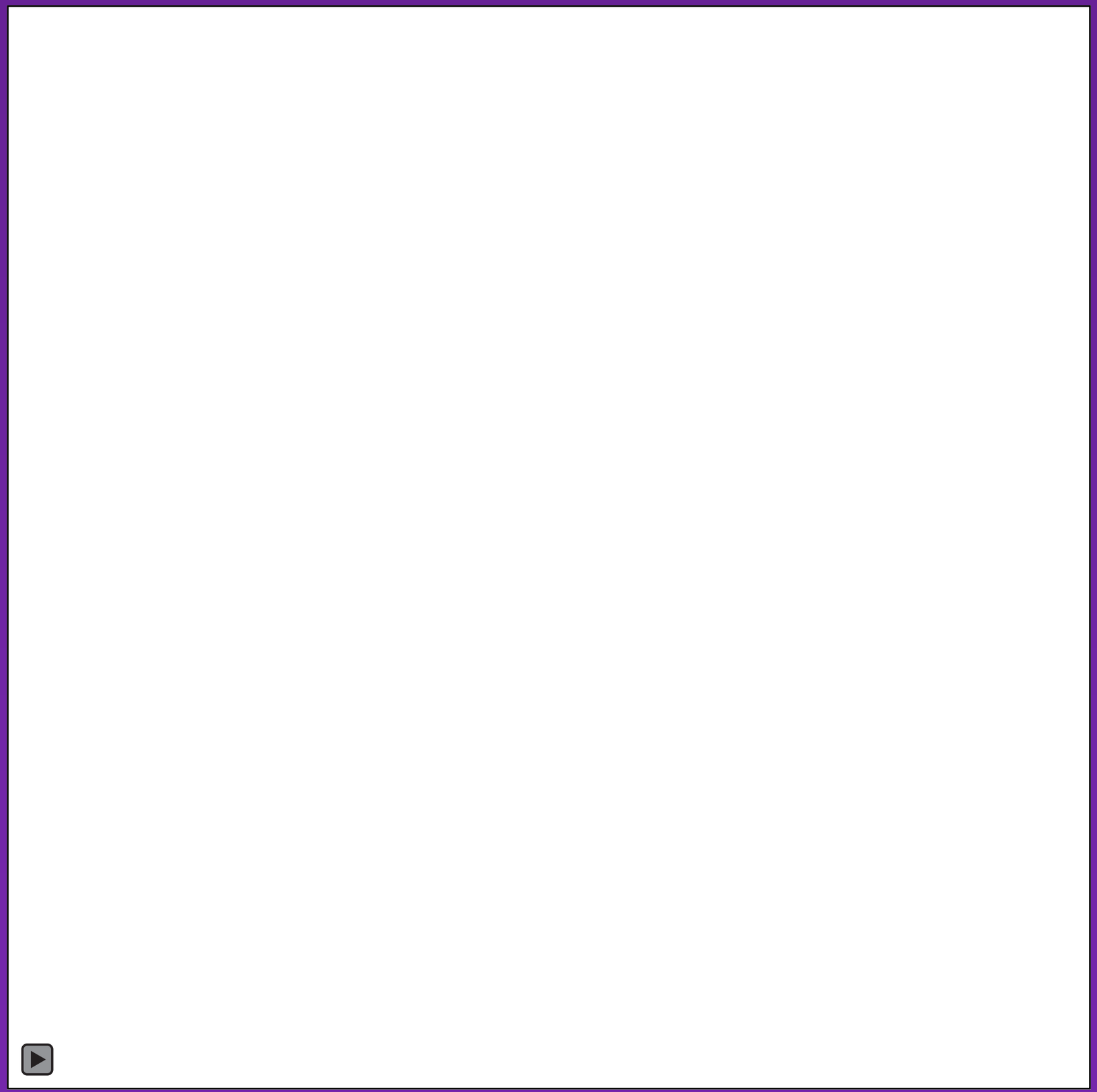
A. Sterling

HMI



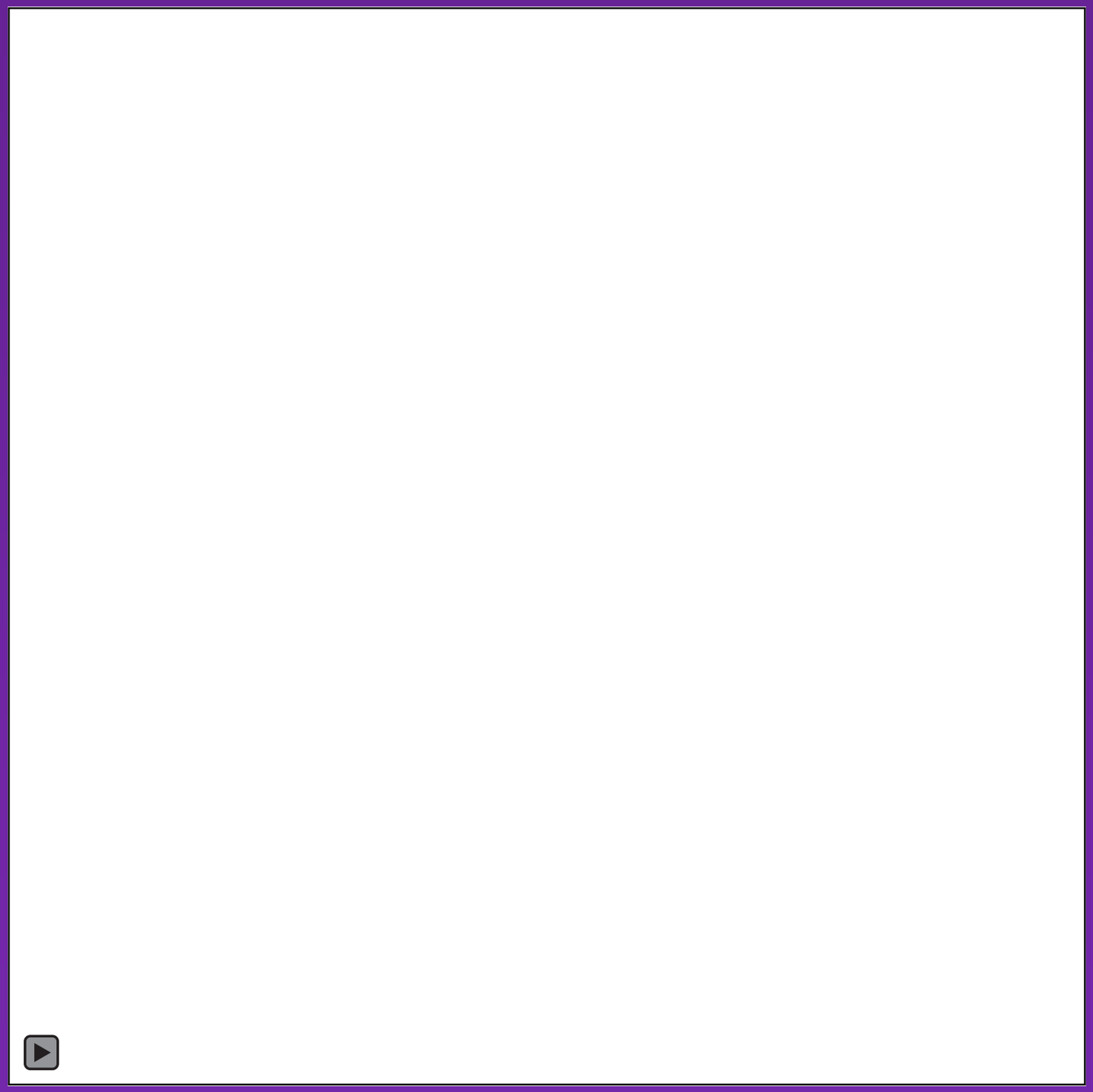
For this jet:

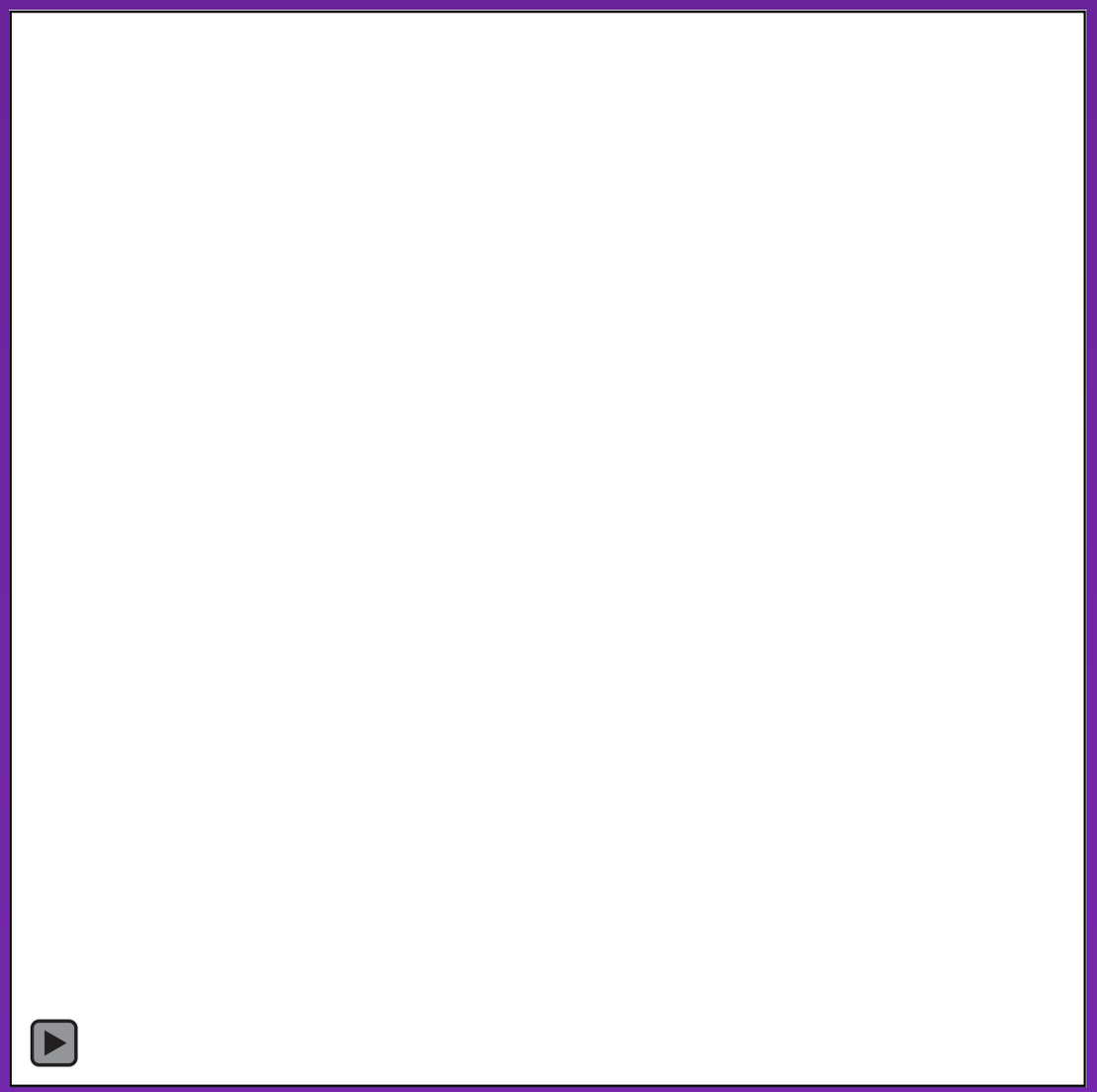
- This jet (actually, a series of jets) is consistent with the minifilament-eruption schematic.
- Minifilament itself however is not as clear as in other cases.
- Occurs at neutral line.
- Cancelation at the neutral line. (Strength? Gradient?).

Where are minifilaments in AR jets?

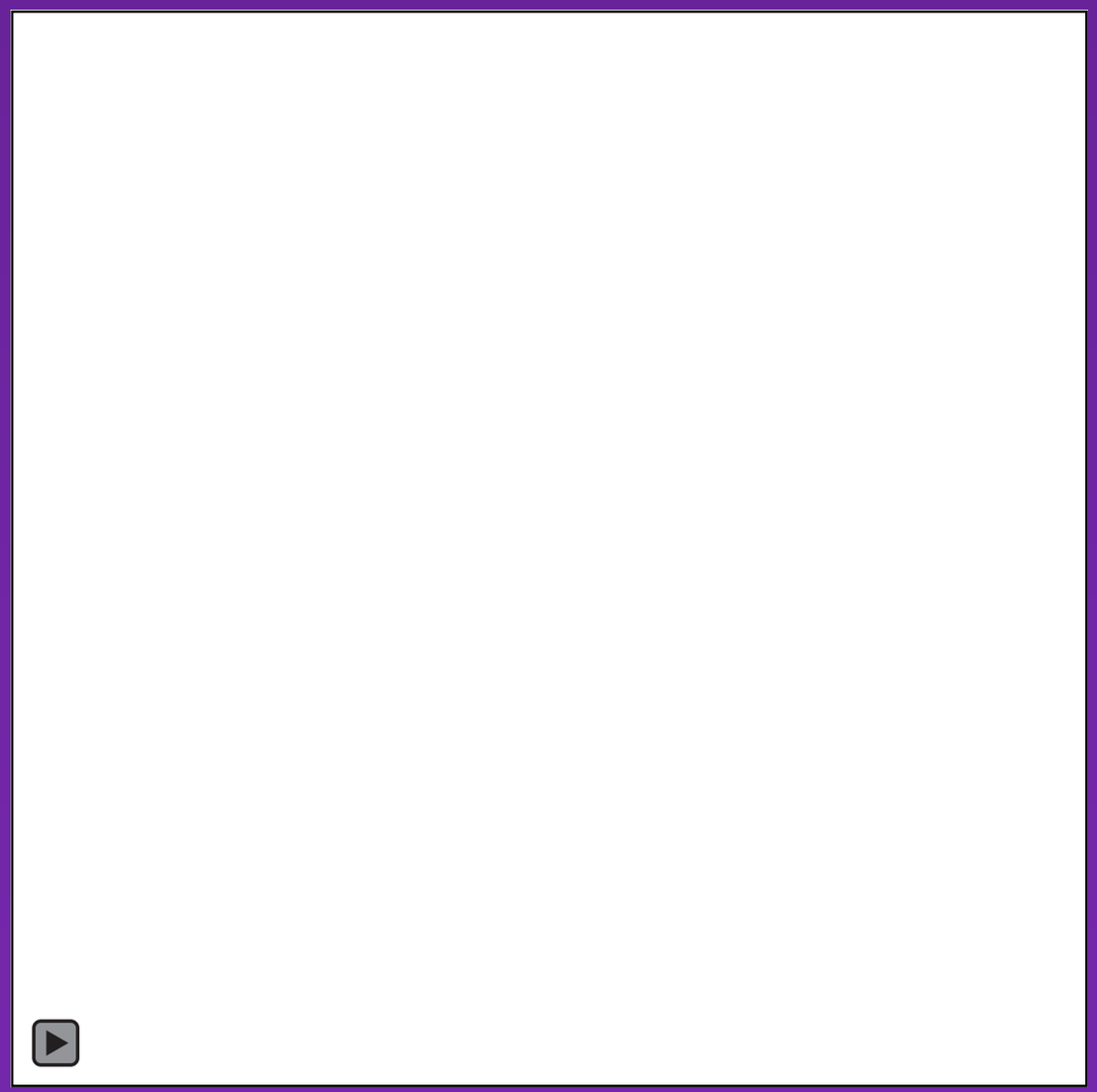
- Magnetic setup suggest minifilament “mechanism” is acting.
- Minifilament itself however is not as clear as in other cases.
  - Several possibilities: Maybe a hot flux rope without cool material, similar to large-scale eruptions without a filament eruption.
  - Cool material may be thin, and partially hidden (Sterling et al. 2017):

Is cool minifilament material hidden by a bright shell?



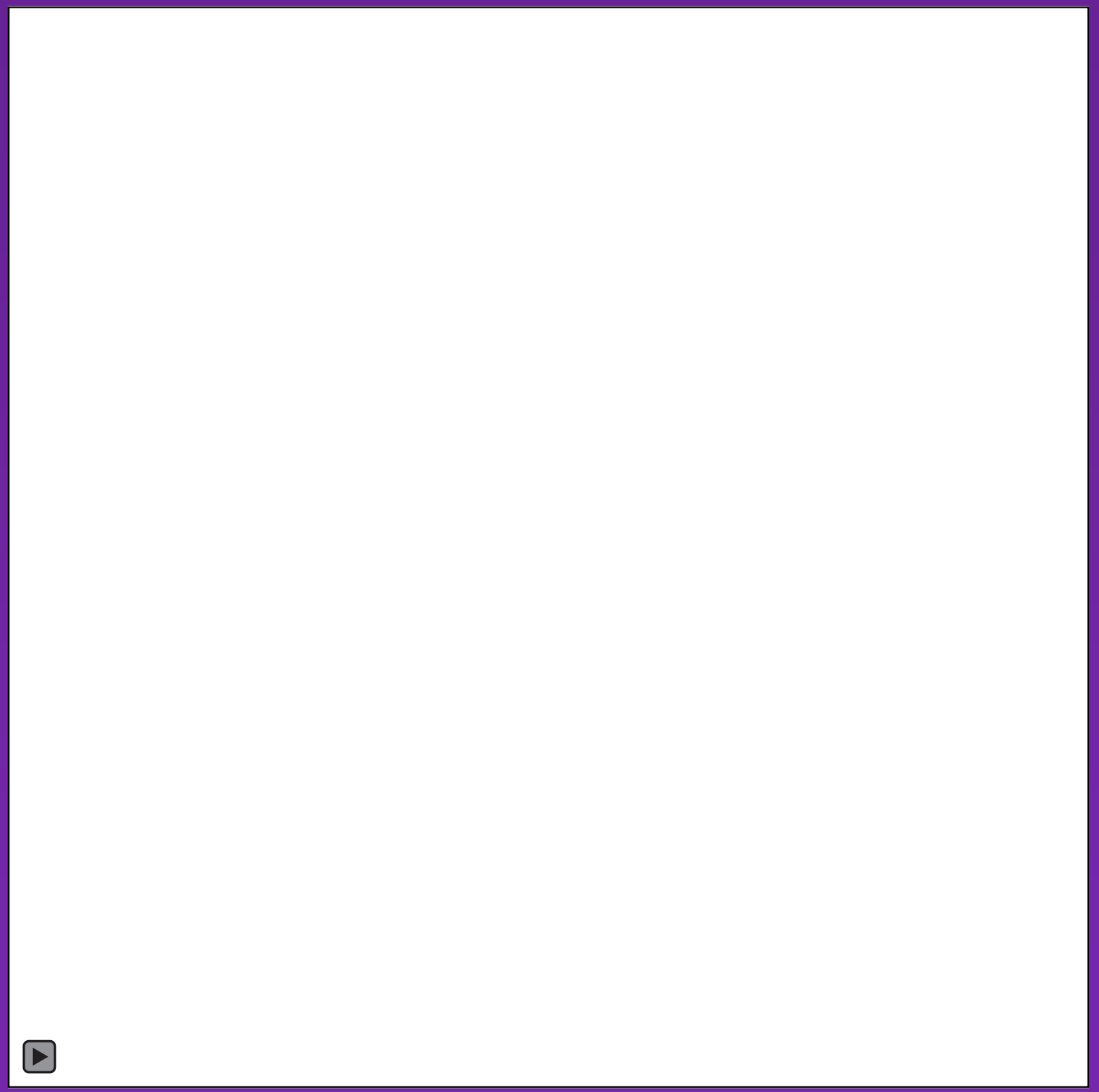


Hinode/XRT



AIA 193

Minifilament “strand” visible from neighboring region, slightly different time



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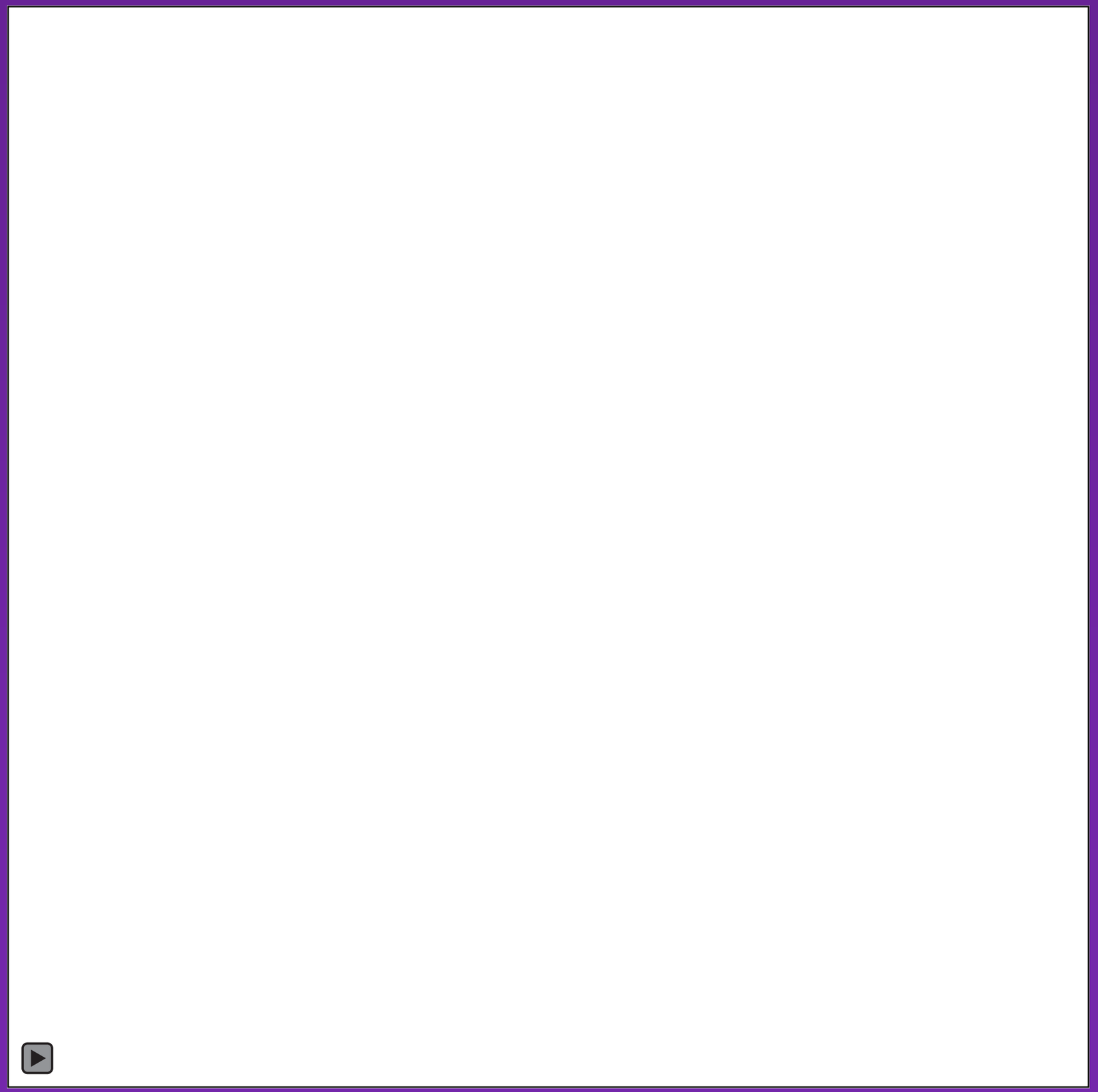
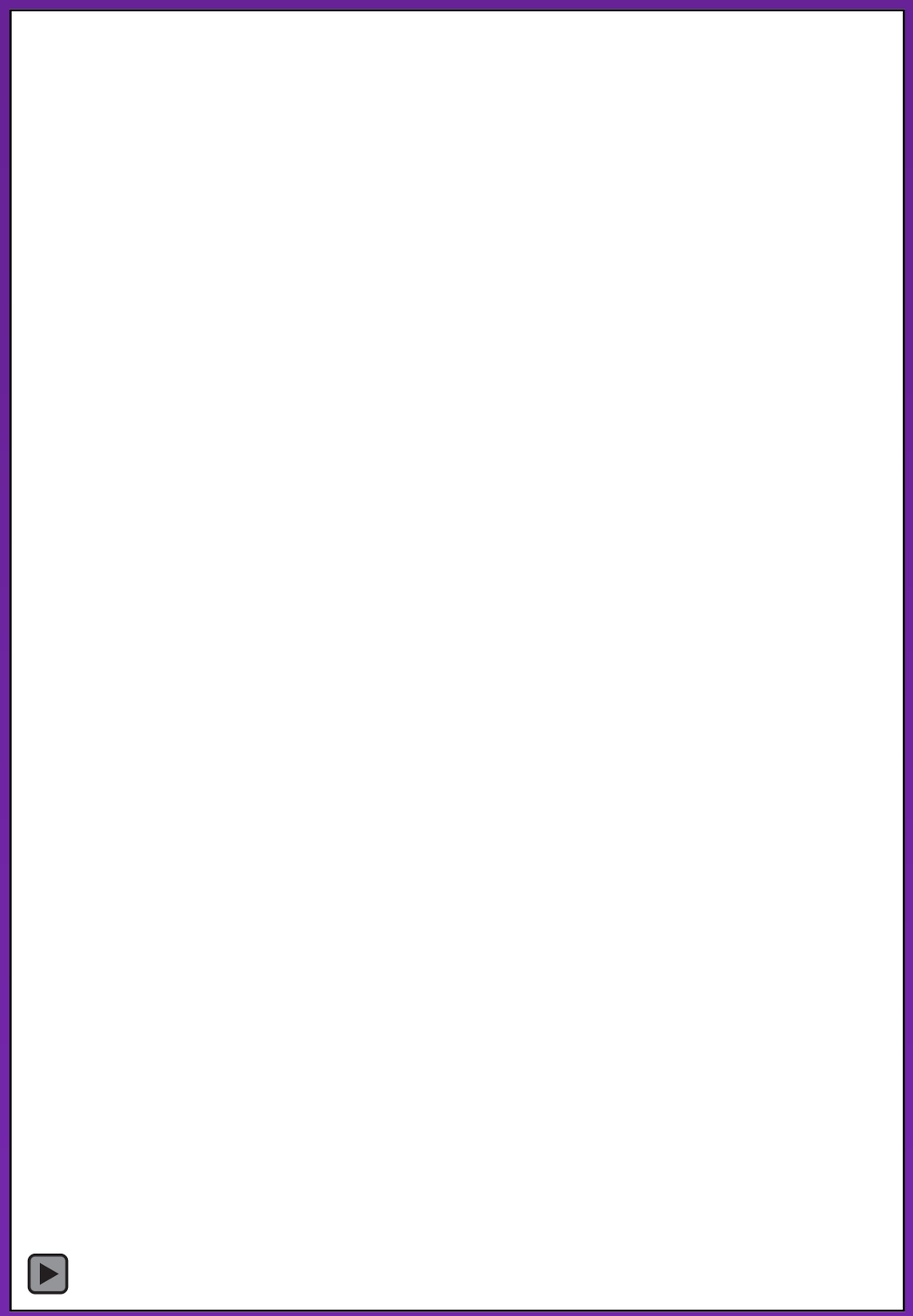
Bright filament “cocoons” envelope some “normal” large-scale eruptions too:

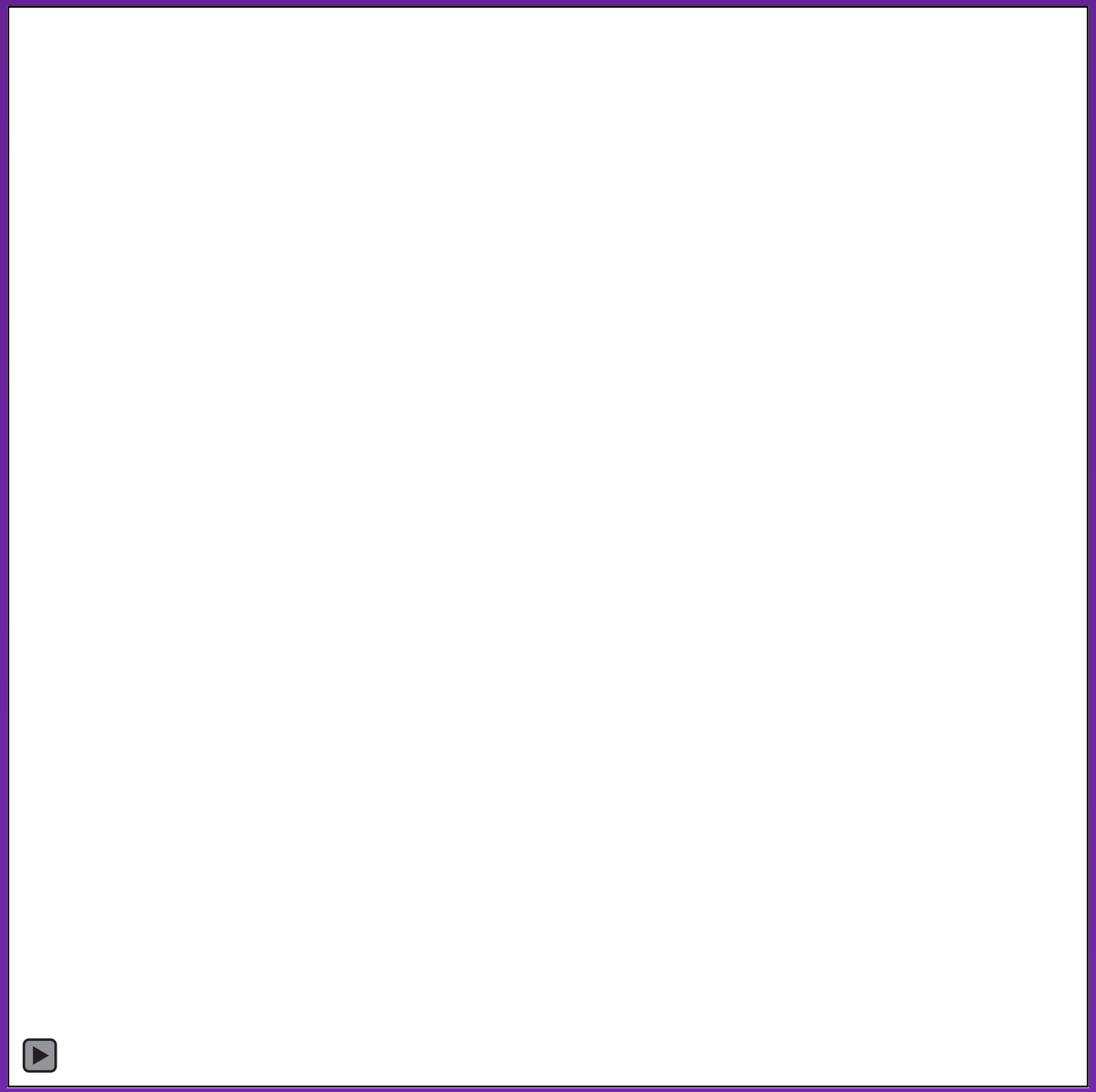


AR Jet: AR 12192, makes CMEs(!), via twist transfer



Panesar et al. (2016b, ApJL)
(Cf. Li et al. 2016.)

AIA 171



Sterling et al. (2016, ApJ)

Sterling et al. (2016, ApJ)

Flux Cancelation Rates:

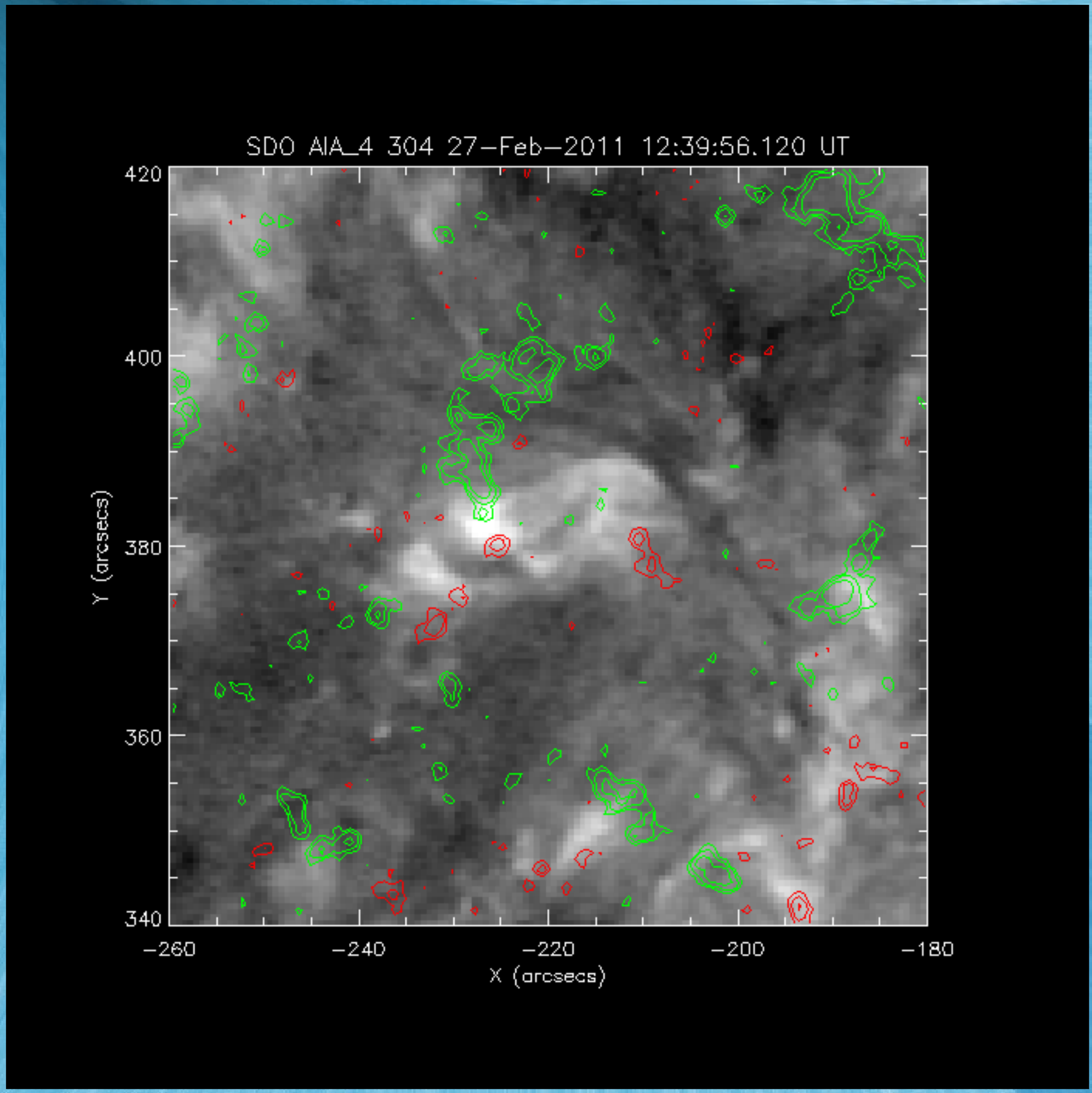
Panesar et al. (2016); Sterling et al. (2017):

- For QS jets (~10 events): ~1.5 x 10^{18} Mx/hr (verify)
- For AR jets (~7 events): ~1.5 x 10^{19} Mx/hr

Summary and Conclusions

- Detailed investigations of several jets.
- Most in CHs and QS fit minifilament picture.
- AR jets are more nuanced: for those we investigated:
  - Visually all fit the minifilament picture, from the magnetic-field setup standpoint.
  - Slower-buildup ones have obvious minifilaments.
  - Faster-buildup ones may have minifilaments, but of a different character than what we're used to (thinner, and maybe hidden by emission). Or maybe a different process.
- All jets occur on neutral lines.
- Frequently (if not always) there is flux cancelation occurring on the neutral lines. There are definitely cases of emergence+cancelation, and there may be cases of minifilament eruption triggered by emerging flux. (Cf. Mulay et al. 2016, others....)
- There are others to be investigated! Several questions regarding jets remain.

Adams et al. (2014): On-disk coronal hole example.



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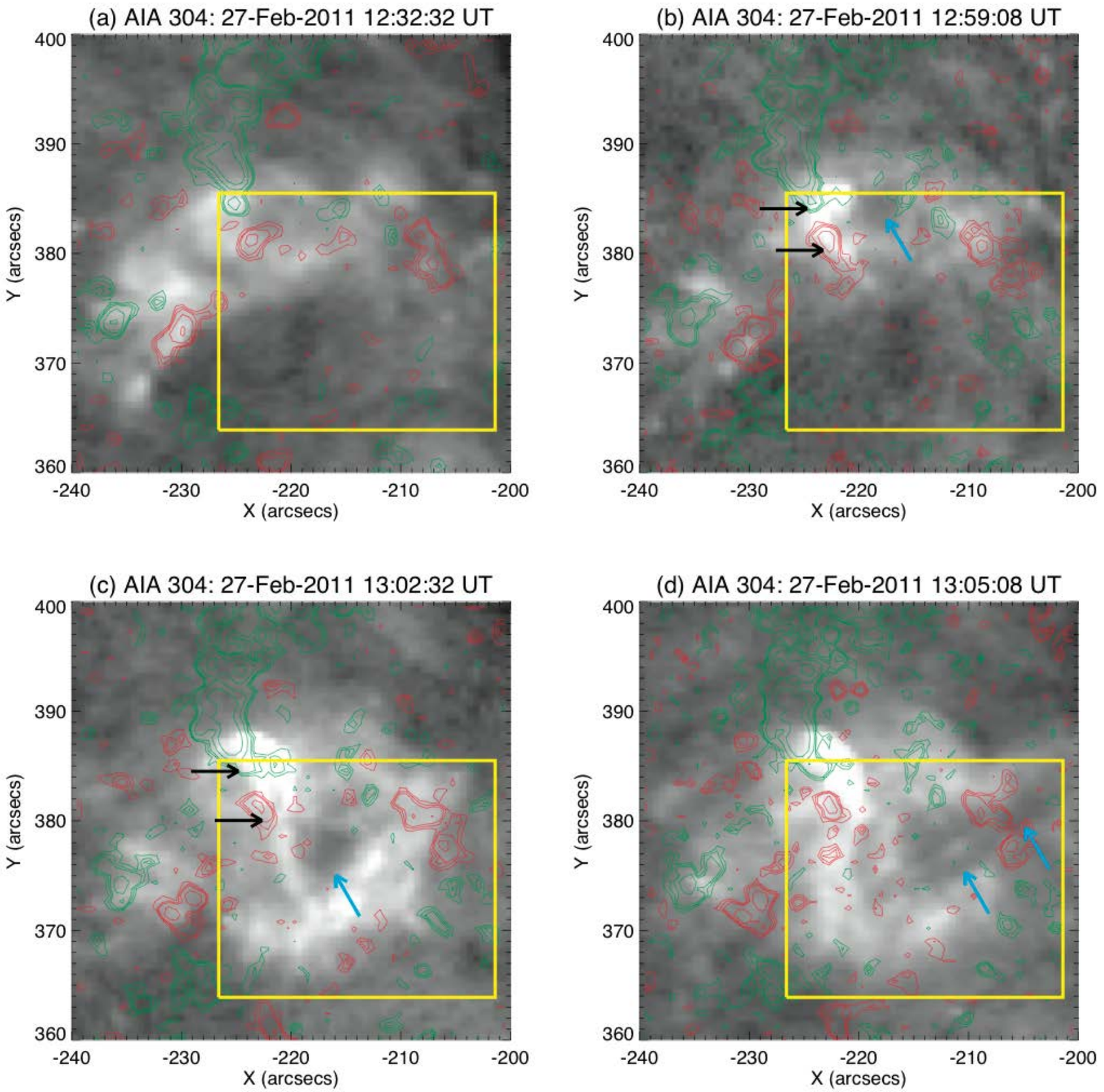
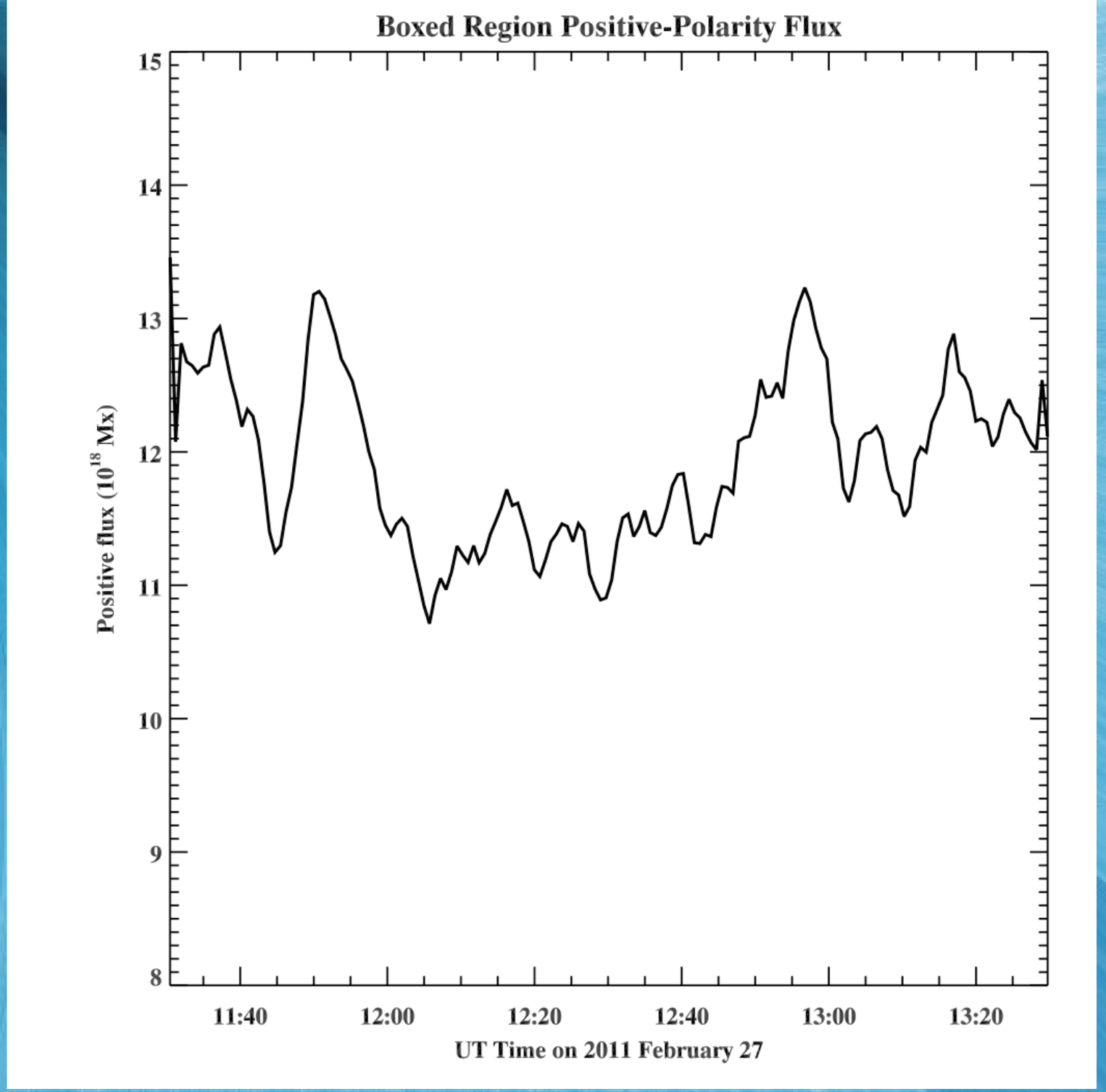

(a) AIA 304: 27-Feb-2011 12:32:32 UT
(b) AIA 304: 27-Feb-2011 12:59:08 UT
(c) AIA 304: 27-Feb-2011 13:02:32 UT
(d) AIA 304: 27-Feb-2011 13:05:08 UT
Y (arcsecs)
X (arcsecs)
400
390
380
370
360
-240
-230
-220
-210
-200

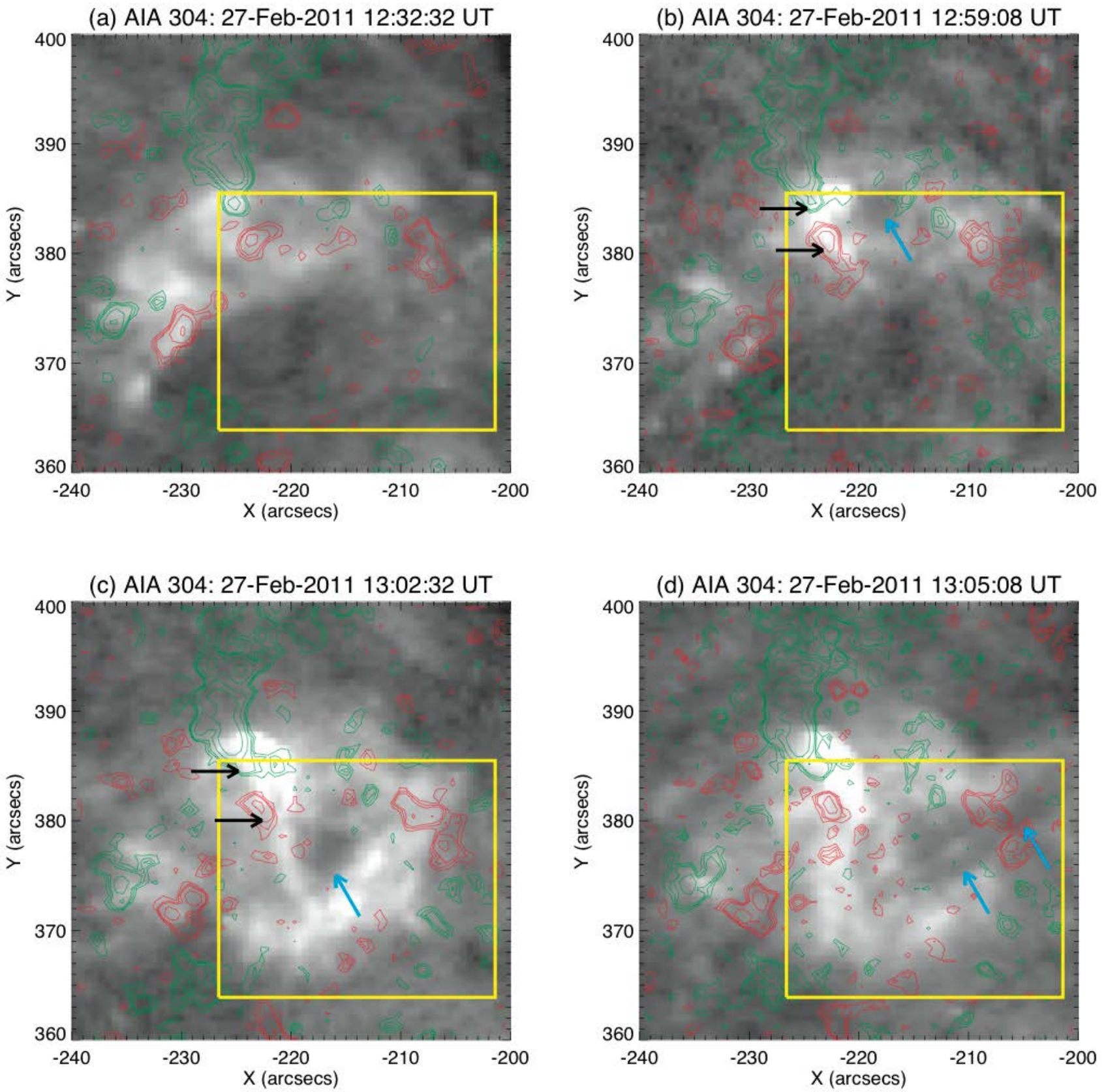
A. Sterling



Variation <~20%; trend <~2×10^{15} Mx/s

=> EF probably not driving the jet

(cf. Chandrashekhar et al. 2014)


(a) AIA 304: 27-Feb-2011 12:32:32 UT
(b) AIA 304: 27-Feb-2011 12:59:08 UT
(c) AIA 304: 27-Feb-2011 13:02:32 UT
(d) AIA 304: 27-Feb-2011 13:05:08 UT
Y (arcsecs)
X (arcsecs)
400
390
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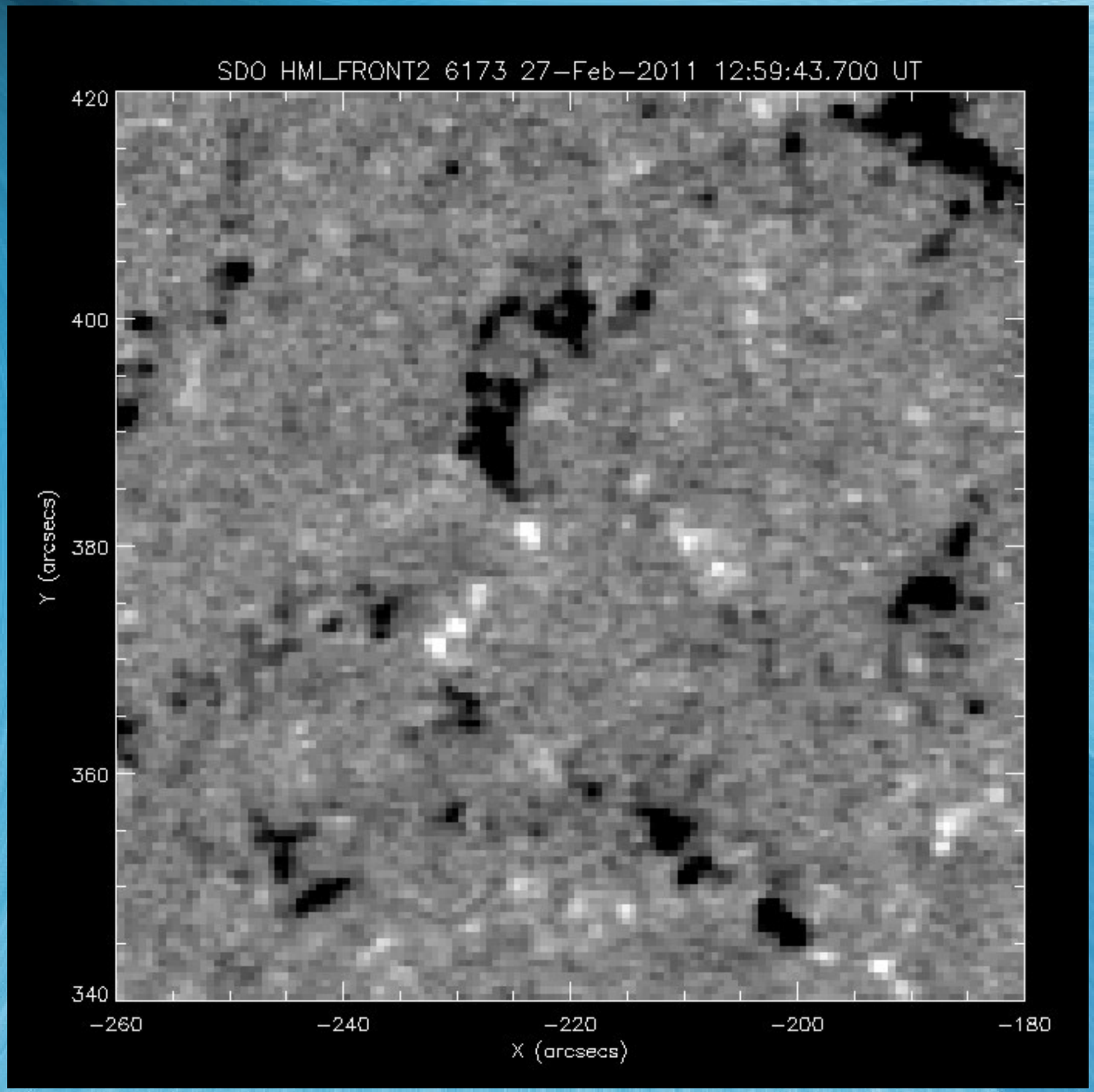
A. Sterling


SDO HMI_FRONT2 6173 27-Feb-2011 12:59:43.700 UT
420
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Y (arcsecs)
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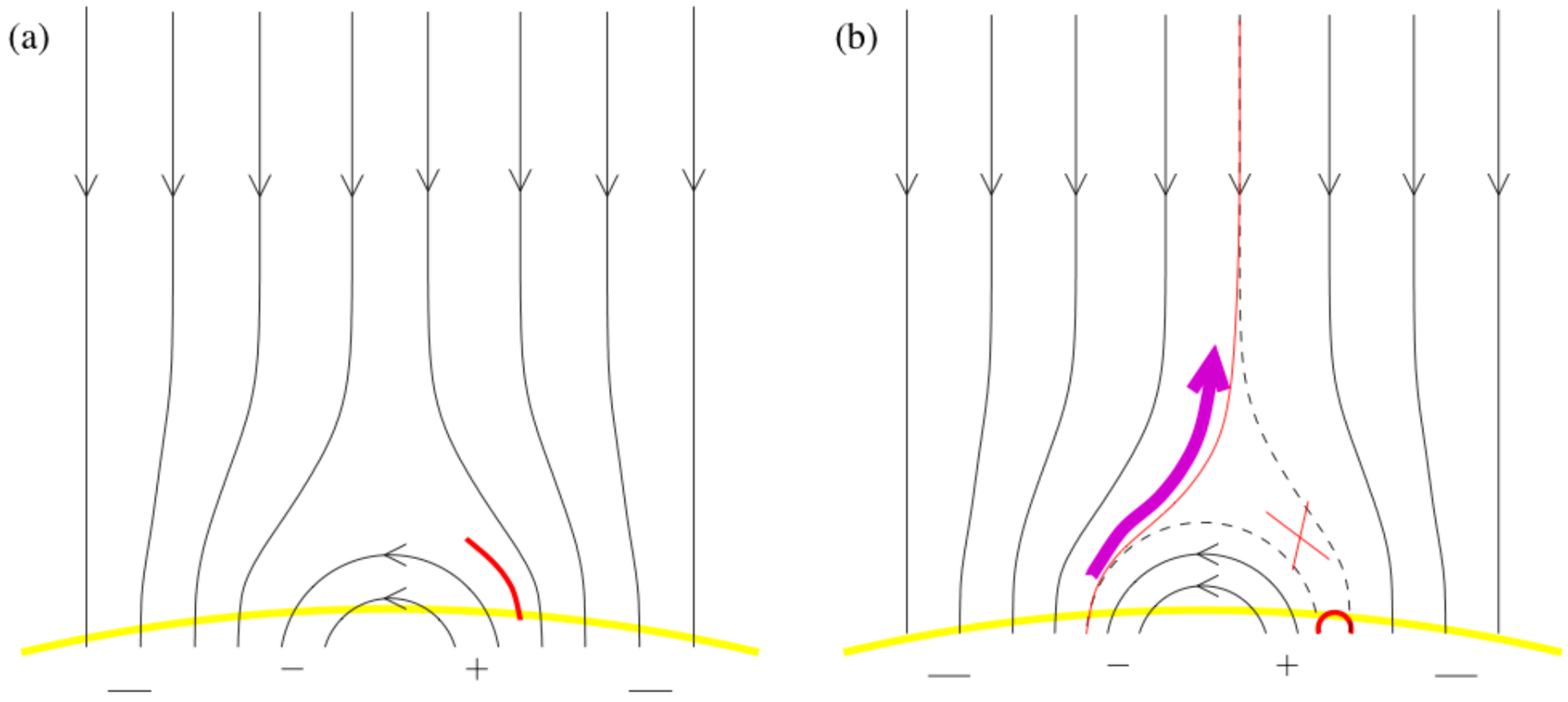
-220
-200
-180
X (arcsecs)

Emerging-Flux Model for (X-Ray) Jets



Shibata et al. 1992.

Supported by numerical simulations: Yokoyama & Shibata (1995, 1996), Nishizuka et al. (2008), Archontis et al. (2013), Moreno-Insertis et al. (2013), Fang et al. (2014), etc.

Moore et al. (2010, 2013): “Standard” and “blowout” jets.